Washington State Department of Transportation

US 12 MP 17.56 Unnamed Tributary to Wenzel Slough (WDFW ID 933616): Final Hydraulic Design Report

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1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the United States Route (US) 12 crossing of Unnamed Tributary (UNT) to Wenzel Slough at milepost (MP) 17.56 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier (ID) 933616) and has an estimated 8,796 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. US 12 is a major transportation corridor with an estimated annual average daily traffic of 22,000 vehicles. Avoidance of the stream crossing is not feasible due to the importance of US 12. WSDOT evaluated the crossing and is proposing to replace the existing crossing structure with a structure designed using the unconfined bridge methodology.

The crossing is located in Grays Harbor County, approximately 1.1 miles east of Satsop, Washington, in WRIA 22. The highway runs in a West-East direction at this location. The UNT to Wenzel Slough generally flows from North to South beginning 0.6 miles upstream of the US 12 crossing (see Figure 1 for the vicinity map). Wenzel Slough eventually drains to the Chehalis River.

The proposed project will replace the existing crossing that consists of two 143-foot-long, 54-inch-diameter, corrugated metal pipe (CMP) culverts with a secant pile bridge designed to accommodate a minimum hydraulic width of 26 feet. The proposed structure is designed to meet the requirements of the federal injunction using the unconfined bridge design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a).

The original Preliminary Hydraulic Report for this site was completed in 2019 by a different engineering group. The requirements and organization of this document has since changed. This Final Hydraulic Report has updated the preliminary work to the extent practical using provided existing condition information from the earlier work on this site. The preliminary data does not always provide the level of detail that is now expected for fish passage work, and so this report may not contain all the information that is provided in more recent reports.

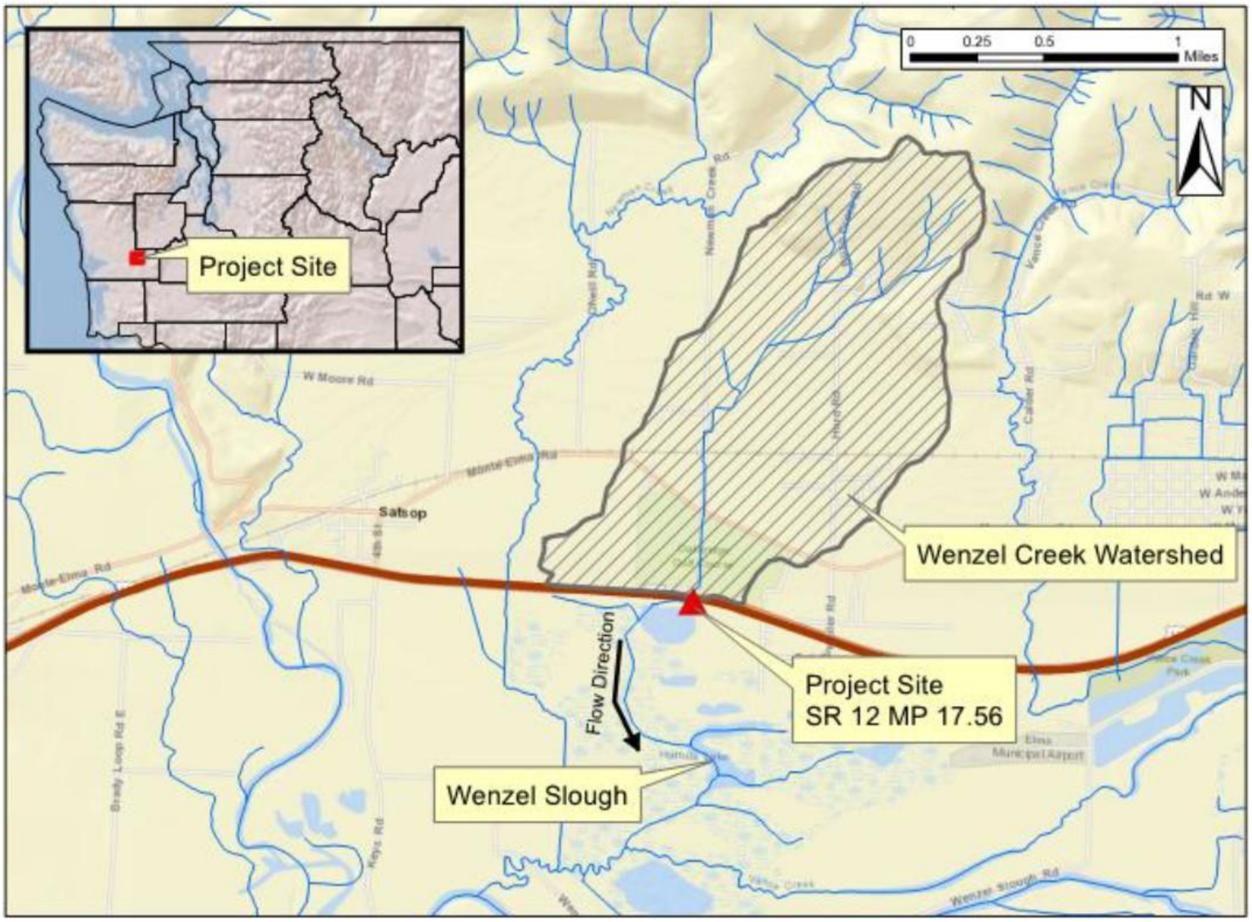

Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, and past records like observations, maintenance, and fish passage evaluation.

2.1 Site Description

WDFW's Inventory Report (2019b) indicates that the existing crossing is a barrier due to low flow depth, with only 67 percent passability for salmonids. This barrier is composed of two 54-inch CMP culverts. The removal of this fish passage barrier will provide an estimated 8,796 LF of potential habitat gain (WDFW 2019a). Historic flooding in the vicinity of the crossing is supported by the presence of nearby houses and structures elevated above the floodplain.

WSDOT Area 4 Maintenance was contacted to determine if ongoing maintenance problems occur at the existing structure due to large woody material (LWM) racking at the inlet or sedimentation. The maintenance representative indicated there was not a record of LWM blockage or sediment removal at this crossing requiring additional maintenance efforts.

2.2 Watershed and Land Cover

The UNT to Wenzel Slough drains 1.52 square miles of relatively flat terrain in the Chehalis River Valley. Slopes within the basin are generally less than 30 percent and the mean basin slope is approximately 4 percent. Elevations in the watershed range from 30 to 300 feet above sea level. The watershed for the UNT to Wenzel Slough was delineated using the U.S. Geological Survey (USGS) StreamStats application (Figure 2). The yellow watershed boundary shown in Figure 2 was modified from the StreamStats delineation (orange boundary) based on flow paths identified from more detailed Light Detection and Ranging (LiDAR) topography and drainage channel mapping discussed further in Section 3.

The southern half of the watershed consists primarily of agriculture and low-density residential development, while the northern half of the basin consists primarily of agriculture and forested land (Table 1). A large portion of the southern quarter of the watershed is Chehalis tribal land. Aerial imagery suggests that land cover and use in the watershed has been relatively unchanged since the 1990s, with only minor increases in the density of residential development (Google 2020). This region is relatively rural and far-removed from any major metropolitan centers, so it is assumed that the current land use trends will continue into the future. A basin map containing topographic information such as contours was not provided in the original PHD.

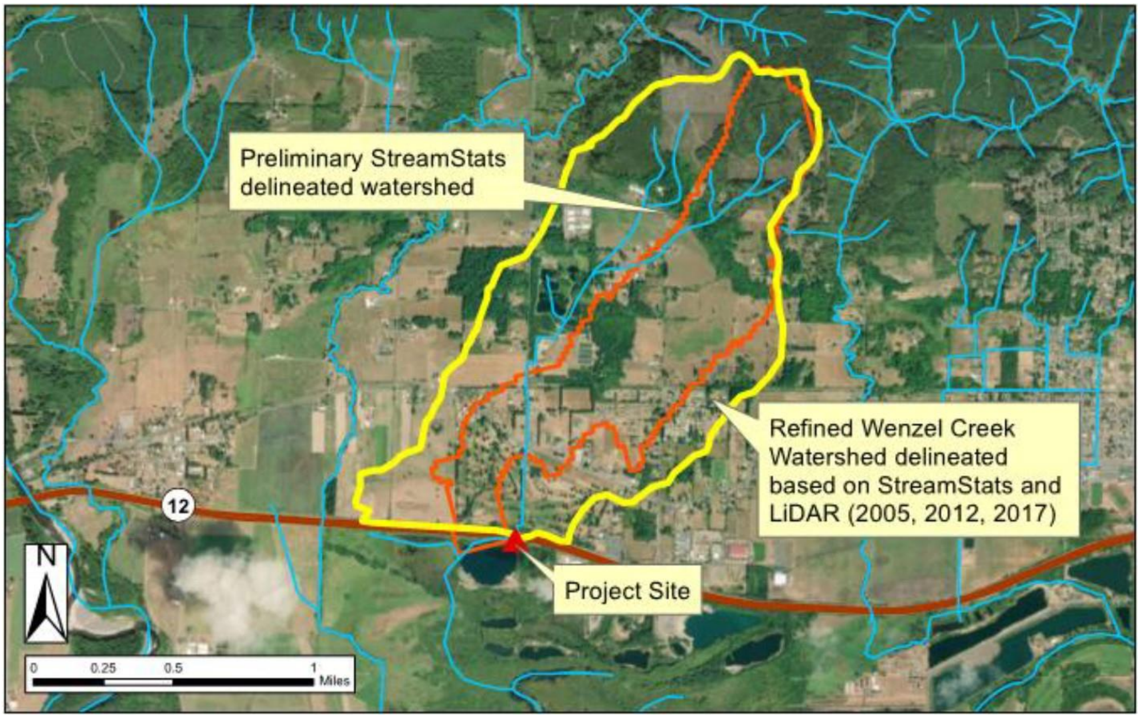

Figure 2: Watershed map

Table 1: Land cover table

Cover/Soil Type	Area (acres)	Percent of Basin
Forest	185.6	19%
Pasture	403.4	41%
Grass	269.2	28%
Impervious	114.5	12%

2.3 Geology and Soils

The upper third of the basin for UNT to Wenzel Slough consists primarily of undifferentiated continental glacial drift, with small areas of Miocene sedimentary rocks. Most of the watershed consists of Pleistocene undifferentiated continental glacial outwash, deposited by meltwater rivers as the Puget Lobe of the Cordilleran Ice Sheet retreated, starting about 16,000 years ago (Gendaszek 2011). The outwash transitions to Quaternary alluvium in the lowest portion of the basin, including the location of the crossing, consisting of floodplain deposits from the modern Chehalis River (Washington Division of Geology and Earth Resources 2016; Schuster 2005). A geologic map was not provided in the original report.

Soils in the UNT to Wenzel Slough basin are widely varied (Figure 3). Grandmound gravelly sandy loam, Nemah silt loam, the Delezene-Rony complex, and the Rony-Gate complex cover the southern third of the basin. The Grandmound gravelly sandy loam is somewhat excessively drained, Delezene-Rony complex is well-drained, and the Rony-Gate complex and Nemah silt loam are poorly drained. The central third consists of Delezene-Rony and Rony-Gate complexes and Xerorthents, and the northern third is primarily Elochoman silt loam and Centralia loam (Natural Resources Conservation Service 2018). The Elochoman and Centralia loams are well-drained. Drainage characteristics near the project site thus vary widely, with poorly drained soils adjacent to excessively drained soils.

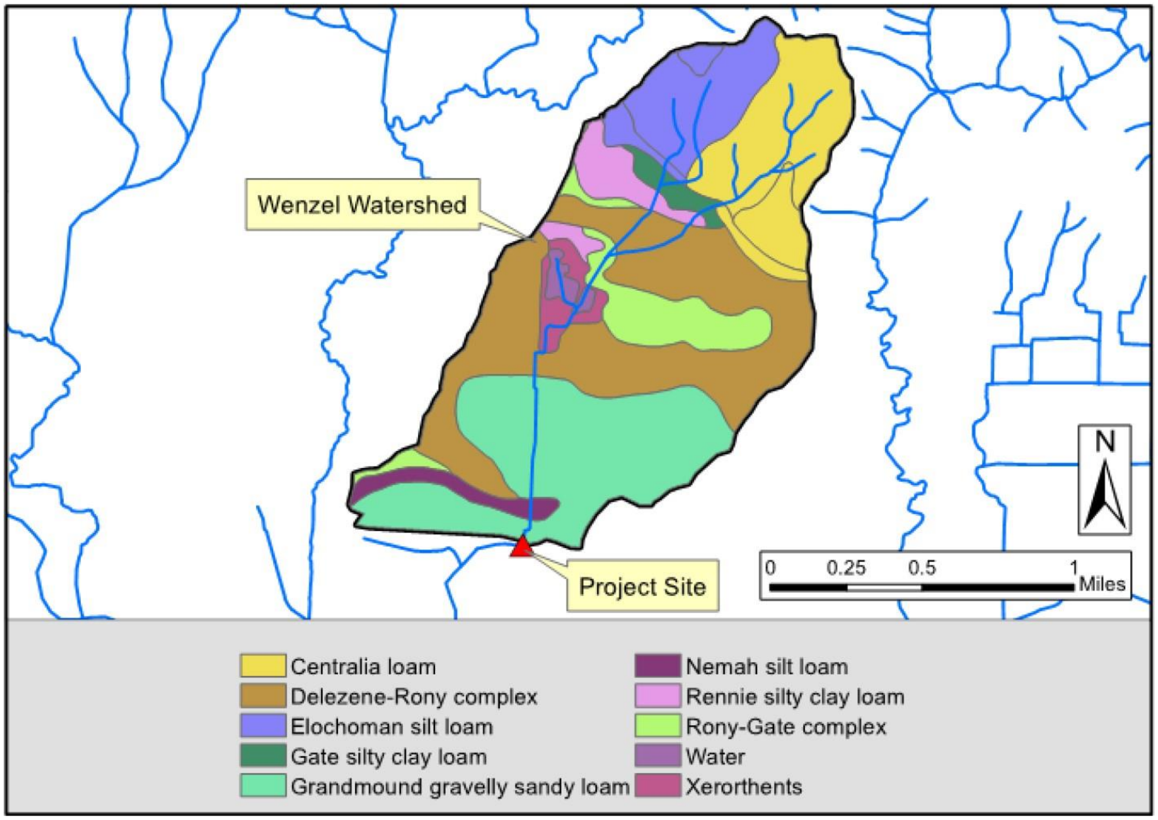

Figure 3: Soils map

2.4 Fish Presence in the Project Area

There are no documented salmonid species in the UNT to Wenzel Slough, but Table 2 lists native fish potentially found in the UNT to Wenzel Slough given its proximity to the Chehalis River, a salmon-bearing stream (WDFW 2015). The UNT to Wenzel Slough could potentially support River Lamprey (*Lampetra avresii*) and Pacific Lamprey (*Entosphenus tridentatus*), chum salmon (*Oncorhynchus keta*) and coho salmon (*Oncorhynchus kisutch*), and coastal cutthroat trout (*Oncorhynchus clarki clarki*) and steelhead trout (*Oncorhynchus mykiss*). Of these, in Washington State, coho salmon and River Lamprey are on WDFW's Priority Habitats and Species list and steelhead trout is a Threatened species under the Endangered Species Act of 1973. Pacific Lamprey and River Lamprey are federal Species of Concern.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho (Oncorhynchus kisutch)	Presumed	Site Assessment Survey (WDFW 2016)	Federal Species of Concern
Steelhead (Oncorhynchus mykiss)	Presumed	Site Assessment Survey (WDFW 2016)	Threatened
Sea-run Cutthroat Trout (Oncorhynchus Clarki clarki)	Presumed	Site Assessment Survey (WDFW 2016)	Not Warranted
Pacific Lamprey (Entosphenus tridentatus)	Presumed*	None Noted	Federal Species of Concern
River Lamprey (Lampetra ayresii)	Presumed*	None Noted	Federal Species of Concern

*From Conservation Biology Institute 2019

2.5 Wildlife Connectivity

The 1-mile-long segment of US 12 containing the crossing of UNT to Wenzel Slough is ranked high priority for Ecological Stewardship and medium priority for Wildlife-related Safety by WSDOT Headquarters (HQ) Environmental Services Office (ESO). Adjacent segments to the west and east ranked high. The high ranks are based on proximity to state-endangered fisher (*Pekania pennanti*) range, connected networks of wildlife habitat, and large blocks of protected land. The large number of connected networks of wildlife habitat are evident when examining the diversity of species represented in the Carcass Removal Database in this three-mile stretch of US 12. Bobcat, coyote, beaver, river otter, bald eagle, owl, and many raccoon carcass removals have been reported. To accommodate wildlife at this crossing, 7 feet was added to the minimum hydraulic opening width (Section 4.2.2).

2.6 Site Assessment

The purpose of this section is to describe the context of the crossing location and to identify factors that should be addressed as part of the project.

2.6.1 Data Collection

The UNT to Wenzel Slough crossing of US 12 was visited by Jacobs Engineering Group, Inc. on August 1, 2019. The initial topographic survey was conducted by WSDOT, with additional survey performed by 1 Alliance Geomatics, LLC in August 2019. David Evans and Associates, Inc. (DEA) completed additional survey in March 2020. The survey data extends 150 feet upstream of the existing culvert inlet and 500 feet downstream of the culvert outlet.

An average bankfull width was determined from measurements taken at 6 locations. A figure showing the locations of the bankfull width measurements was not included in the PHD and is therefore unavailable for this report. More detailed information about channel geometry is presented in Section 2.7.2. No pebble counts were conducted due to the abundance of fines.

Figure 4: Reference reach location

2.6.2 Existing Conditions

The existing crossing is composed of twin 54-inch-diameter 144-foot-long CMP culverts that flow south under US 12. Although the two culverts provide high-flow capacity and additional large culverts were observed upstream of the US 12 crossing, no flowing water was present during the site visit. The reach immediately upstream of the culverts was obscured by dense vegetation, and the channel is poorly defined, as seen in Figure 5. A flow path was identified by damp soil, but vegetation and organic debris accumulation in the channel bottom suggested little to no flow in the recent past. The absence of bed scour near the entrance to the culverts may indicate they are backwatered at high-flow events, perhaps due to influence from the Chehalis River and/or nearby Newman Creek, which also crosses US 12 over 3,600 feet to the west of the UNT to Wenzel Slough. Farther upstream, the channel is contained in a ditch that crosses Oakridge Golf Course. This ditch appears to be routinely maintained and unlikely to migrate.

Downstream of the culvert outlet, as seen in Figure 6 and Figure 7, the channel flows approximately 10 feet until it emerges into a vegetated area between the highway and a gravel access road parallel to the highway. During the August 1 site visit, the channel was assessed for approximately 1,200 feet downstream until the field staff encountering a gate. The ground in this area was wet and muddy, with some standing water in several locations. Live and dead willows cover the channel and banks, creating some small woody material. The flow path bends west and continues between the gravel road and US 12 prism for at least 1,000 feet, eventually becoming lost in the vegetation as the road traverses the margin of a large wetland area. Some evidence of high flows crossing the gravel roadway approximately 500 feet downstream of the culvert outlet were noted.

Based on the field observations of the ditch-shape of the channel and lack of well-defined bankfull indicators, and a review of Federal Emergency Management Agency (FEMA) floodplain mapping, the channel and its hydraulic conditions at this crossing appear to be influenced more by the extended floodplain from the Chehalis River during high flows than runoff from the relatively small watershed. The combination of these conditions may explain why this creek lacks a formal name. Due to the typical low flow in the channel, fish likely only access the crossing during the wet season (September through May).

The overall impression is that this area was likely wetland prior to the influence of infrastructure. The UNT to Wenzel Slough was likely created as a ditch to drain area for agriculture and the golf course, and provide ditch conveyance for US 12.

Figure 5: Eastern culvert inlet

Figure 6: Western (left) and eastern (right) culvert outlets

Figure 7: Western culvert outlet

2.6.3 Fish Habitat Character and Quality

During the August 2019 field visit some standing water was present, but no flowing water was observed. Because coho salmon rear in rivers for a year before migrating to the ocean (Washington State Conservation Commission 2001), dry channel conditions during the summer eliminate the possibility of rearing coho salmon or resident trout utilizing the habitat upstream or downstream of the crossing.

Downstream of the crossing, the UNT to Wenzel Slough has been highly modified from its natural condition but the channel does contain some LWM and riparian vegetation. The existing bed material would not be suitable for salmonid spawning (WDFW 2019a).

Further downstream, the creek flows through a straightened channel into a large wetland area with no defined channel. This wetland area provides conveyance and flood storage for the Chehalis River during high flows, and it has potential to provide high-quality spawning and rearing.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

No LWM was present in the reference reach, though the channel bottom was littered with leaves and small twigs. Downstream of the crossing, no LWM was present, but at least four pieces of small woody material was present in the channel. This material was typically 3 to 4 inches in diameter and 6 to 10 feet long. One of the pieces was a live willow, approximately 20 feet long and 4 inches in diameter, that had fallen into the channel and was still rooted with new leaf growth. Several other trees had exposed roots that interacted with the channel.

Immediately upstream of the culvert, the ground was damp during the August 1, 2019, field visit, and appears to have wetland characteristics. Downstream of the culvert, the channel emerges onto the floodplain of the Chehalis River, with both open-water and scrub-shrub wetlands immediately south of the access road that forms the left bank (looking downstream) of the channel. Excavation in this area is likely to encounter shallow groundwater, even in late summer conditions.

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the channel both vertically and laterally of UNT to Wenzel Slough.

2.7.1 Reference Reach Selection

Selection of a representative and undisturbed reference reach was challenging given the impacts to the channel (primarily straightening) both upstream and downstream of the US 12 crossing. Three reaches were considered as potential reference reaches: far upstream of the US 12 crossing through the golf course, between the golf course and US 12 crossing, and downstream of the US 12 crossing.

Downstream of the crossing the channel is poorly defined, despite being confined to a straight corridor between the highway fill and a gravel access road, before eventually entering a large wetland complex. This downstream channel is less maintained than the ditched segment upstream and therefore has a more natural riparian area. However, channel straightening, an adverse gradient, and wide bankfull width (BFW) measurement were the reasons this was not selected as the reference reach. Also, the WDFW Inventory Report (2019a) indicates the existing crossing is a barrier due to low flow depth. If the downstream channel were used as a reference reach, the wider BFW would exacerbate the existing passage problems, resulting in even shallower depths at all flows.

Details about the reach between the golf course and the US 12 crossing were not supplied in the PHD.

Ultimately, a segment of the far upstream reach was selected as the reference reach. The location is depicted in Figure 4. Through this reach, the channel is generally poorly vegetated and confined in a straight road-side ditch for at least a half mile, through the golf course, across Monte-Elma Road, and beyond some railroad tracks. The 200-foot reach downstream of the golf course and approximately 200 feet upstream of the culvert inlet includes good canopy cover and a moderate understory of woody shrubs. While the ditch is oversized, soil and vegetation indicators were identified within the ditch that suggested an approximate bankfull flow level. The BFW was measured to be 9 feet, and the slope is estimated to be 0.2 percent. Photographs of the reference reach were not included in the original PHD.

2.7.2 Channel Geometry

The existing channel geometry is challenging to characterize. Upstream of the US 12 crossing, most of the channel is maintained as a straight, oversized ditch. Changes in vegetation and soil characteristics suggested a 9-foot BFW (Figure 8) and a slope of 0.2 percent in the reference reach compared to the twin culvert’s slope of 0.3 percent. This is consistent with the BFW documented by WDFW in their Fish Passage Inventory Report (WDFW 2019a). The exact locations of the BFW measurements reported in the PHD are unknown. Additional BFWs measured for the FHD were based on survey data.

Upstream of the culvert, there is a roughly 100-foot reach of channel that ends in a ditch that runs parallel to US 12. This short segment between the ditch and the culvert inlet has a poorly defined channel and exhibits a concave profile, forming a single, long pool nearly 2 feet deep (See Section 2.6.2, Figure 9). Surveyed channel widths in this area ranged from 10 to 20 feet, with a very broad floodplain.

Downstream of the crossing, the channel runs between the highway prism and a small dirt access road. Surveyed BFW averaged 20 feet, as seen in Figure 9, with a slight riffle/pool sequence. The wide BFW is presumably caused by frequent flooding from the Chehalis River, which inundates this area at the 2-year and larger events. The thalweg approximately 300 feet downstream of the culvert was surveyed to be 0.85 foot higher than the culvert invert. The access road is relatively low, typically 1 to 2 feet above the channel thalweg, and there was evidence of overtopping.

After observing conditions in both reaches, a bankfull elevation was chosen based on sparse, poorly defined vegetation and soil indicators at a cross section approximately 300 feet upstream of the US 12 crossing. The BFW in the reference reach was measured as 10 feet. Additional flow enters the UNT to Wenzel Slough downstream of the reference reach from a culvert approximately 110 feet upstream of the US 12 crossing. To compensate for this additional flow, the design bankfull width was increased to 12 feet. A summary of BFW measurements is provided in Table 3.


Figure 8: Measuring BFW in ditched section upstream of crossing

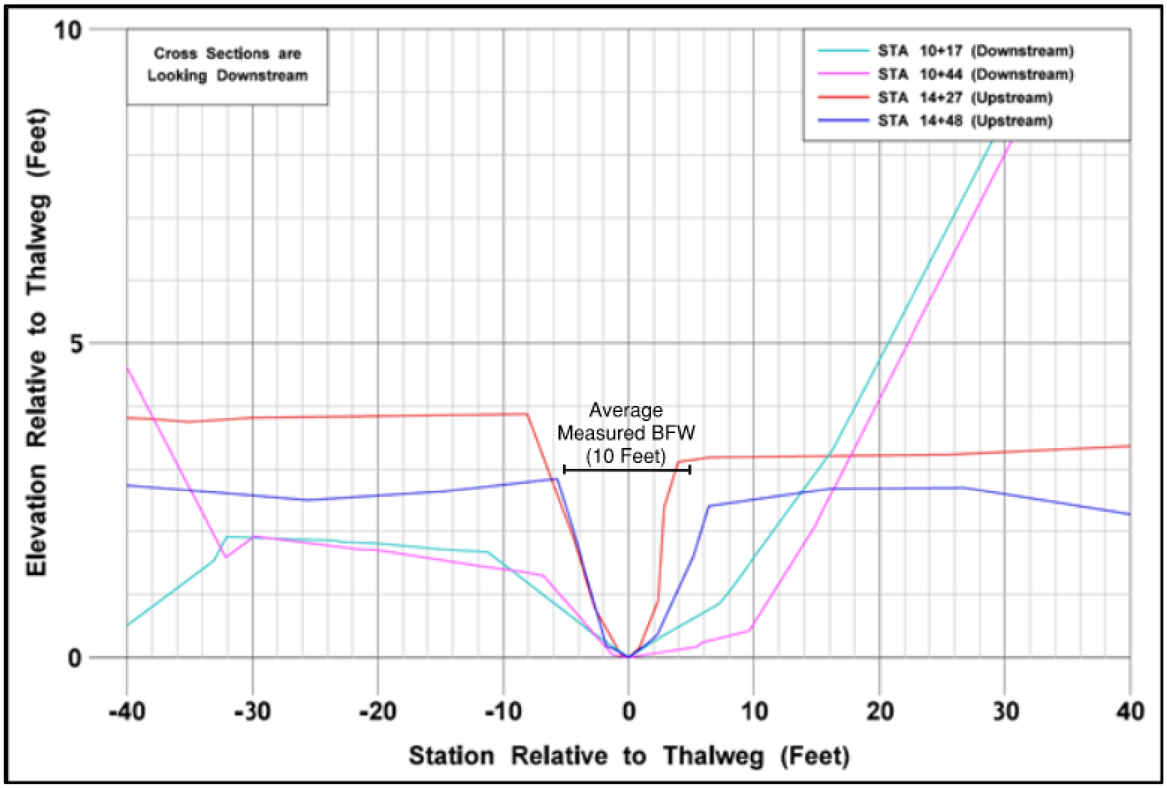

Figure 9: Existing cross-section examples using existing conditions stationing

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in measured average?	Location
1	10	Yes	300 ft upstream of culvert
2	9	No	Upstream
3	10 - 20	No	Between ditch and culvert inlet
4	20	No	Downstream
Measured average	10		
Design average	12		

2.7.2.1 Floodplain Utilization Ratio

The WCDG presents three methodologies for designing a bridge crossing - stream simulation, confined bridge design, and unconfined bridge design. The method to be used is defined by the Floodplain Utilization Ratio (FUR). The FUR is defined as a ratio of the flood-prone width (FPW) divided by the BFW. The FPW is the water surface width at the 100-year flood. A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel. Modeling was not used to determine the FUR in the PHD, instead it was decided that the existing flat topography upstream and downstream of the culvert and backwater from the Chehalis River all contribute to a FUR much greater than 3.0. The unconfined bridge design was deemed the most appropriate for this crossing because the FUR is greater than 3.0.

2.7.3 Sediment

The creek bed both upstream and downstream of US 12 was dominated by fine sediment as observed during the August 2019 site visit (Figure 10 and Figure 11). Because of the abundance of fines, a pebble count was not conducted.

Figure 10: Channel characteristics upstream of crossing

Figure 11: Channel characteristics downstream of crossing

2.7.4 Vertical Channel Stability

The channel gradients upstream and downstream of the US 12 crossing are relatively flat. Figure 12 shows a general slope of 0.43 percent upstream of US 12. The downstream reach is a straightened channel that flows between US 12 and a service road that parallels the highway. This reach is flat until it crosses the service road over 2,000 feet downstream of the US 12 crossing and drops into a wetland complex. The US 12 crossing sits in depression along the channel that is presumed to be a result of scour generated by backwater from the Chehalis River during high flow events. Despite a supply of glacial outwash, neither aggradation nor degradation are expected at the US 12 crossing, as discussed in Section 7.2.

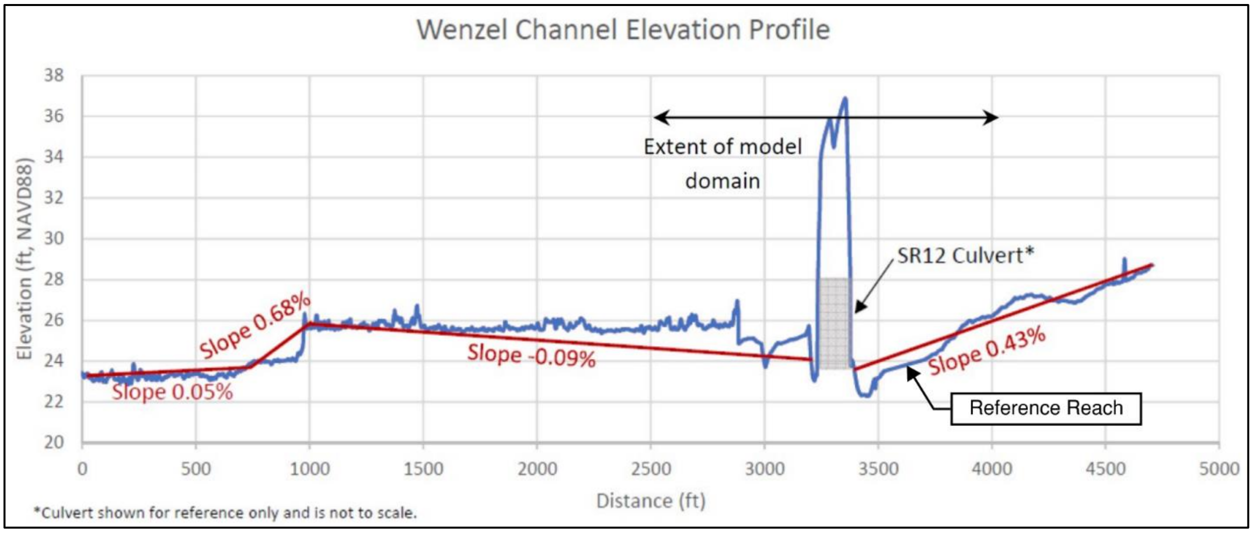

Figure 12: Watershed-scale longitudinal profile

2.7.5 Channel Migration

Little evidence of channel migration is present at the site. Both upstream and downstream channels appear maintained, keeping the channel in its present planform. Upstream of the US 12 crossing, most of the channel is maintained as a straight, oversized ditch. No floodplain flow paths were observed upstream of the crossing.

The downstream channel is also straight and is little more than a ditch between US 12 and a gravel access road. The road accesses a WDFW property and appears regularly maintained preventing channel migration. There is evidence the access road overtops at higher flows. Overall, the channel is at low risk for channel migration.

3 Hydrology and Peak Flow Estimates

The UNT to Wenzel Slough is a tributary Wenzel Slough, which itself is a tributary to the Chehalis River, which is approximately 2.6 miles downstream of the US 12 crossing. During major floods, such as the 100-year event, backwater from the Chehalis extends through Wenzel Slough up to and north of the US 12 crossing, according to FEMA floodplain mapping (see Appendix A).

The Chehalis watershed has a west-coast, marine-type climate, with mild and relatively dry summers, and mild but wet winters. The average annual precipitation for the UNT to Wenzel Slough is 66 inches of rainfall, mostly between the months of October and March.

There is no historical flow data for the UNT to Wenzel Slough as there is no USGS nor Washington State Department of Ecology stream gage installed in or near the basin. Because the UNT to Wenzel Slough is an ungaged stream, the peak discharges at the crossing were calculated using the USGS's regional regression equations (Mastin et al. 2017) and corroborated with calculations using MGSFlood.

For the regional regression method, USGS's StreamStats (2016), a web-based application, was used to delineate the drainage basin and determine basin characteristics. Per StreamStats, the calculated drainage area upstream of the UNT to Wenzel Slough crossing is 0.71 square mile and has a mean annual precipitation of 65.9 inches. The delineated drainage basin from StreamStats was based on a 30-meter Digital Elevation Model (DEM), resulting in a coarse, inaccurate watershed. The StreamStats watershed delineations are often inaccurate in areas with low relief where surface water hydrology has been heavily modified, such as in the southern end of the watershed for the UNT to Wenzel Slough. A more accurate watershed was determined using the Spatial Analyst tools in ArcGIS and the 2012 Grays Harbor LiDAR dataset. The revised basin delineation has a drainage area of 1.52 square miles. The regression equations were applied to the revised basin delineation

Because the UNT to Wenzel Slough watershed is moderately developed with considerable impervious surface, and because the USGS regression equation does not account for land cover, continuous simulation hydrologic modeling was also performed using MGSFlood software. For the MGSFlood method, U.S. Department of Agriculture soil type maps were superimposed over current aerial imagery of the basin. Overlapping regions were used to develop estimates of land use for each of the MGSFlood soil type designations and provided as input to the model. The MGSFlood watershed characteristics are listed in Table 4.

Table 4: Watershed characteristics for MGSFlood

Cover/Soil Type	Area (acres)	Percent of Basin
Till Forest	5.9	1%
Till Pasture	83	9%
Till Grass	27	3%
Outwash Forest	179.7	18%
Outwash Pasture	320.4	33%
Outwash Grass	242.2	25%
Impervious	114.5	12%
Total	972.7	-

The USGS StreamStats equations produce a 90 percent prediction interval in addition to the estimated flood discharge, acknowledging a wide uncertainty range in the application of the StreamStats equations. The USGS StreamStats equations simplify hydrology to use inputs of watershed area and mean annual precipitation only. However, the hydrologic process is much more complicated, with strong influence by factors such as ground cover and soil infiltration rates. Peak StreamStats discharges for the watersheds, for both the estimated flood discharge (Qu) and 90 percent confidence level prediction interval (PI_L and PI_u), as well as MGSFlood results for the UNT to Wenzel Slough are summarized in Table 5.

Table 5: Comparison of StreamStats and MGSFlood peak flows for the tributary to Wenzel Slough

Mean Recurrence Interval	**UNT to Wenzel Slough Predicted Flow (cfs)**	
	StreamStats (PIL) Qu (PIU)	**MGSFlood**
2	(16) 68 (295)	98
10	(33) 140 (601)	210
25	(40) 180 (820)	247
50	(44) 212 (1016)	306
100	(49) 247 (1243)	435

PI_L: Prediction Interval, 90% confidence level, lower
Q_u: Estimated flood discharge
PI_U: Prediction Interval, 90% confidence level, upper

The MGSFlood values are less than the StreamStats PI_u, but greater than the StreamStats estimated flood discharge (Q_u). While the watershed is within the appropriate size range for StreamStats, the watershed is generally more developed than many of the gauged watersheds used to develop the StreamStats regression equations and, as such, the estimated flood discharge value (Q_u) is considered too low.

Larger drainage basins are present in either direction of the UNT to Wenzel Slough, to the east Vance Creek (5.0 square miles) and to the west, Newman Creek (10.2 square miles). Vance Creek is spatially and physically separated from interacting with the project site, but Newman Creek's floodplain is hydraulically connected to the UNT to Wenzel Slough during higher floods and introduces additional discharge above the culvert. Additional information regarding the hydraulic connectivity of Newman Creek and UNT to Wenzel Slough can be found in Section 5. The flow output from StreamStats were used to calculate the peak flow values for Newman Creek. Table 6 shows the peak flow values selected for the hydraulic analysis of UNT to Wenzel Slough and Newman Creek.

The PHD did not include flows for a 500-year storm event and the final design team does not have access to the ArcGIS delineated basin or the MGSFlood file. As a result, a logarithmic trendline was used to extrapolate the PHD results to obtain a 500-year peak flow for the UNT to Wenzel Slough. To determine the Newman Creek 500-year flow, the PHD StreamStats results were replicated. The 500-year flows are shown in Table 6.

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 435 cubic feet per second (cfs) for the 100-year storm event and 1,256 cfs at Newman Creek's 100-year storm event. The projected increase for the 2080 100-year flow is 48.5 percent, yielding a projected 2080 100-year flow of 646 cfs and 1,865 cfs for the UNT to Wenzel Sough and Newman Creek, respectively.

Table 6: Peak flows for the Unnamed Tributary to Wenzel Slough at US 12

Mean recurrence interval (MRI) (years)	UNT to Wenzel Slough (cfs)	Newman Creek (cfs)
2	98	370.4
10	210	729.6
25	247	928
50	306	1088
100	435	1256
500	517	1640
Projected 2080 100	646	1865

4 Water Crossing Design

This section describes the water crossing design developed for US 12 Milepost (MP) 17.56 UNT to Wenzel Slough, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for UNT to Wenzel Slough at US 12 MP 17.56. This design does not propose variability in vertical, cross-sectional shape, and alignment. The stream will make its own variability after construction.

4.1.1 Channel Planform and Shape

The channel bottom will be two feet wide in order to maintain flow depths adequate for fish passage as the existing crossing is a fish passage barrier because of depth. From the channel bottom, the side slopes will have a slope of 2H:1V to match the design bankfull width of 12 feet with a channel depth of 2.5 feet. There are 10:1 floodplain benches on either side of the channel. The left-bank floodplain bench is 8.5 feet wide to accommodate wildlife and the right-bank floodplain bench is 5.5 feet wide. Beyond the floodplain benches grading is variable to match the existing ground.

Figure 13 shows the proposed channel and water surface elevations (WSE) upstream of the proposed crossing. The 2-year WSE overtops the channel banks by a few tenths of a foot, providing a little more than 2.5 feet of flow depth. This is comparable to the flow depths provided by the existing channel for the 2-year event. The 2-year top width for existing conditions is much wider than proposed conditions. The proposed channel concentrates low flows to promote fish passage during low flow conditions.

The completed survey does not include the reference reach, so no comparison between the reference reach and the proposed grading can be made. However, the reference reach measurements were adjusted for design. As stated in Section 2.7.2, a design BFW 2 feet larger than the average measured BFW was used to account for additional flow that comes in upstream of US 12. So, a comparison of the proposed design to the reference reach may not be comparative. Figure 14 shows a comparison between the proposed channel grading and the existing channel upstream and downstream of the crossing. The proposed channel is very similar to the existing channel upstream of the US 12 crossing, with a bankfull width of approximately 10 feet. The proposed channel is very different than the channel downstream of the crossing, where the tributary transitions into a wetland.

After construction, the low-flow channel is expected to self-adjust based on hydraulic interaction with channel complexity elements as discussed in Section 4.3.2. The thalweg will connect habitat features together so that the project does not become a low-flow barrier.

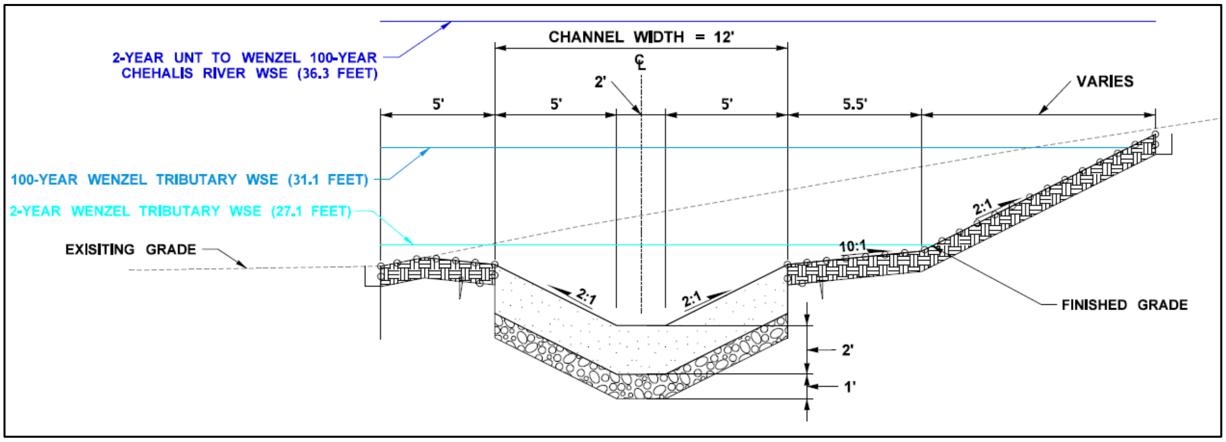

Figure 13: Design cross section with peak upstream WSEs (STA 12+80)

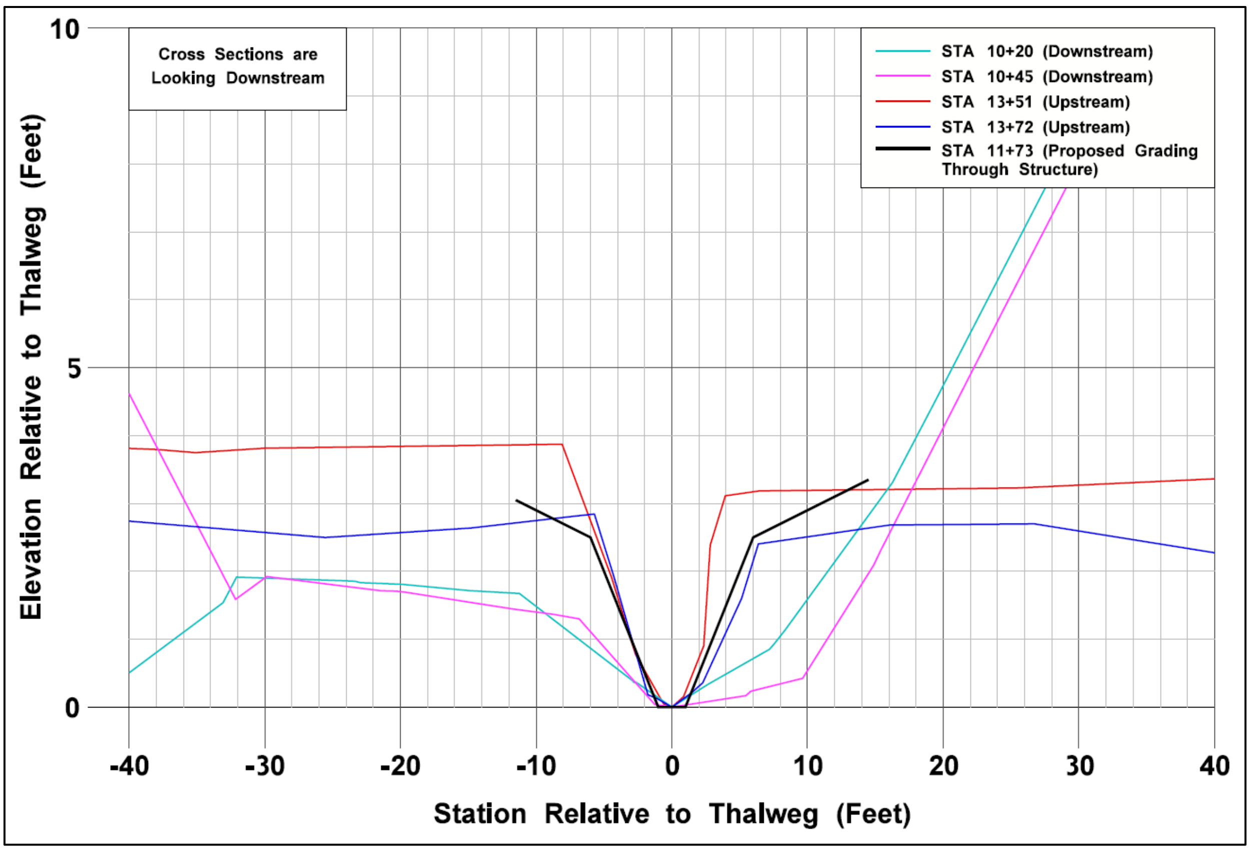

Figure 14: Proposed cross section superimposed with existing survey cross sections using proposed alignment stationing

4.1.2 Channel Alignment

The proposed alignment shifts the crossing inlet approximately 54 feet west of the existing culvert inlet to facilitate construction. By shifting the inlet, the crossing can be constructed without having to divert the channel. This shift introduces sinuosity upstream of the crossing. The crossing outlet is shifted further to the west than the inlet, causing the proposed alignment to be skewed 20 degrees compared to the existing alignment, which is perpendicular to US 12. The channel immediately downstream of the existing culvert outlet will be preserved to provide additional backwater habitat. This channel will be graded appropriately to ensure fish cannot become stranded. In total, the proposed alignment requires 348 feet of grading. Appendix F contains design drawings with the proposed plan, profile, and typical cross section.

4.1.3 Channel Gradient

The proposed design slope is 0.22 percent. The slope immediately upstream of the crossing is 0.2 percent. This results in a slope ratio of 1.1. This is less than the slope ratio of 1.25 required by the stream simulation design methodology. The proposed gradient mimics the reference reach’s estimated gradient of 0.2 percent.

Glacial outwash present throughout the basin provides an abundant supply of sediment, which could result in aggradation in specific scenarios. However, aggradation is not expected for reasons discussed in further detail in Section 7.2.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 15 for an illustration of the minimum hydraulic opening, hydraulic width, freeboard, and maintenance clearance terminology.

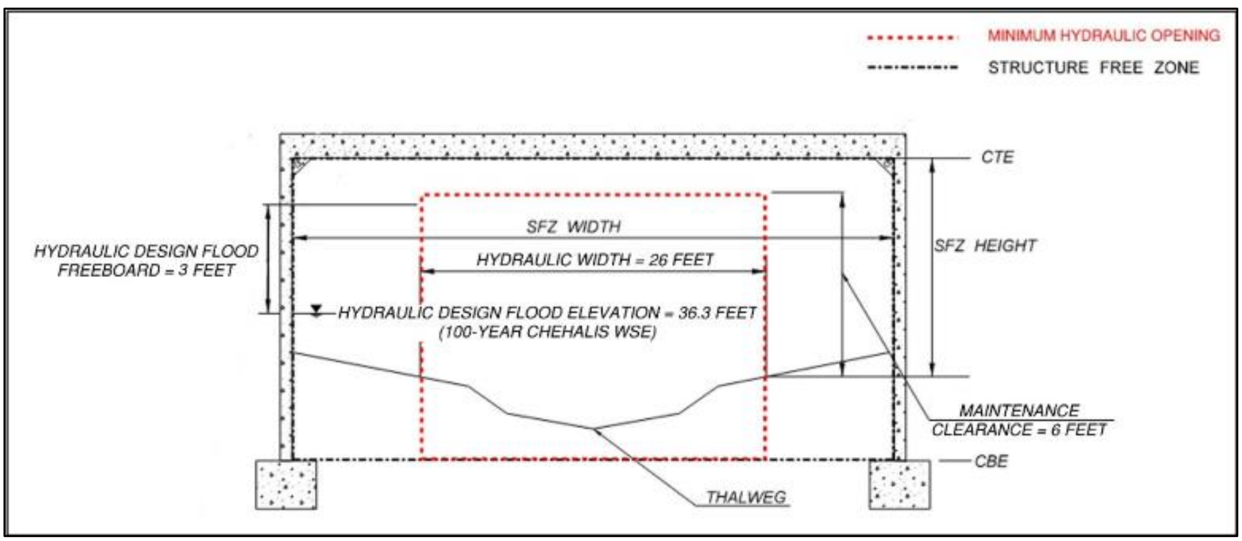

Figure 15: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the unconfined bridge method was determined to be the most appropriate at this crossing (see Section 2.7.2.1). However, due to the unrealistically large hydraulic openings required by this methodology, stream simulation was used to inform the sizing of the minimum hydraulic opening (see Section 4.2.2).

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 14 feet was determined to be the minimum starting point.

The unconfined bridge methodology requires a comparison of velocities from the natural condition to velocities in the proposed conditions to determine the velocity ratio. These velocities should be similar. However, backwater from the Chehalis River at this crossing causes a unique situation. When there is significant flooding along the Chehalis River, the flood water extend to US 12 and beyond. This pushes Chehalis River flood water up through the US 12 crossing backward against normal flow from the unnamed tributary. This effect can be significant under the right circumstances causing high velocity reverse flow through the hydraulic opening.

During preliminary analysis, hydraulic modeling evaluated velocity ratios through a range of hydraulic openings up to 60 feet. Because the Chehalis River backwater is so overwhelming, larger openings did not reduce velocity through the structure, but rather, the larger hydraulic openings increased scour. In consultation with co-managers, it was agreed that the velocity ratio requirement would not be satisfied because of these unique conditions. Ultimately, due to the unique characteristics of the site the hydraulic width was determined using the stream simulation design methodology, with additional hydraulic width added for wildlife crossing.

The WCDG recommends sizing the span of the proposed structure based on the agreed upon BFW, with the span being 1.2 x BFW + 2 feet (WCDG Equation 3.2). Given the field-measured width of 10 feet, this equation suggests a structure width of 14 feet. Due to the complex hydrologic conditions at the site (Section 5) and the length-to-width ratio being more than 10:1, the minimum width was increased by 30 percent, to 19 feet in the PHD. After the completion of the PHD, however, the minimum width was increased again to 26 feet to accommodate wildlife crossings with concurrence from the co-managers.

The expected channel migration is limited, as discussed in Section 7.1.

The projected 2080 100-year flow event was evaluated to determine the impacts of climate change on velocities through the proposed crossing. Table 7 compares the velocities of the 100-year UNT no Chehalis, projected 2080 100-year UNT no Chehalis, and 2-year UNT 100-year Chehalis events. No size increase was determined to satisfy velocity ratio requirements, so the hydraulic opening will remain at 26 feet and no changes will be made for climate change. For detailed hydraulic results see Section 5.4.

Table 7: Velocity comparison for 26-foot structure

Location	100-year UNT velocity (ft/s)	Projected 2080 100-year UNT velocity (ft/s)	2-year UNT 100-year Chehalis velocity (ft/s)
Reference reach (STA 15+07)	0.3	0.3	1.2
Upstream of structure (STA 12+80)	1.3	1.5	4.5
Through structure (STA 11+57)	6.6	8.1	7.6
Downstream of structure (STA 10+52)	3.5	4.4	1.8

Note: hydraulic data taken from the peak time step (8:00) in the hydraulic model.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 8.

The minimum required freeboard at the project location, based on bankfull width, is 2 feet above the 100-year WSE (Barnard et al. 2013, WSDOT 2022a). However, WSDOT requires 3 feet of freeboard at all bridge crossings. Since the structure at this crossing is a bridge, the design meets 3 feet of freeboard.

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. Due to the overwhelming impact of the Chehalis River on water surface elevations at this crossing, the freeboard requirements are based on the 100-year Chehalis River WSE of 36.3 feet. A model that can provide WSEs for Chehalis flows under a 2080 projected 100-year event does not currently exist, and therefore cannot be used in the hydraulic design.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or large woody material (LWM). If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 do not include elements of significant size and will not need to be maintained with machinery. If it is practicable to do so, a minimum maintenance clearance of 6 feet is recommended for maintenance and monitoring purposes but is not a hydraulic requirement. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width. The proposed crossing will provide over 15 feet of clear height which is sufficient for maintenance clearance.

In order to meet the vertical clearance requirements for this crossing, the roadway is being raised approximately 5 feet at the crossing location.

Table 8: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	11+00	12+37
Thalweg elevation (ft)	23.4	23.7
Highest streambed ground elevation within hydraulic width (ft)	26.8	27.1
100-year WSE (ft)	36.3	36.3
Required freeboard (ft)	3	3
Recommended maintenance clearance (ft)	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	39.3	39.3
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	32.8	33.1
Required minimum low chord (ft)	**39.3**	**39.3**
Proposed design low chord (ft)	**39.3**	**39.3**

4.2.3.1 Past Maintenance Records

WSDOT Olympic region maintenance records were unavailable for this crossing.

4.2.3.2 Wood and Sediment Supply

The watershed is primarily residential and agricultural land cover. Historical aerial imagery suggests that the northern 0.4 square miles of the watershed has been actively managed for logging since at least 1990. So, there is a potential upstream supply of LWM. The channel passes through a golf course upstream of the US 12 crossing, which would likely remove any LWM upstream of the crossing from the channel. The largest risk of LWM transport at the US 12 crossing is during a Chehalis River backwater event. During the 100-year Chehalis backwater event, it is estimated that logs up to 4 feet DBH and 20 feet long could be transported in floodwaters near the crossing.

As stated in Section 2.2, aerial imagery shows land cover and land use has been relatively unchanged since the 1990s, with only minor increases in the density of residential development. Thus, it is assumed that land use will remain generally constant in the future. Glacial outwash present throughout the basin provides an abundant supply of sediment, which could result in aggradation. However, as described in Section 7.2, aggradation is not a risk at this crossing due to the hydraulic conditions.

4.2.4 Hydraulic Length

The proposed bridge is 137 feet long. This is a single structure that accommodates both the eastbound and westbound lanes of US 12.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve US 12 through this corridor.

4.2.6 Structure Type

A bridge is recommended by Headquarters Hydraulics for this crossing because the channel is unconfined (Section 2.7.2.1). The proposed bridge will use secant piles to account for the deep scour that is anticipated at this crossing.

4.3 Streambed Design

This section describes the streambed design developed for UNT to Wenzel Slough at US 12 MP 17.56.

4.3.1 Bed Material

The development of the proposed streambed mix followed methods recommended in the WCDG (Barnard et al. 2013) for sizing streambed material in culverts and the WSDOT Hydraulics Manual (WSDOT 2022a). However, the bed design at this crossing is unique because of the anticipated scour issues that are discussed in Section 7. The proposed design incorporates 2 feet of native streambed material on top of several layers of coarser sediment and slash material. The total depth of the proposed streambed sediment through the proposed structure is 6 feet (see Appendix D).

The proposed 2-foot top layer was selected based on field observations of existing substrate. The existing streambed material within the reference reach consists entirely of fines (see Section 2.7.3), so no pebble counts were conducted. Any bed material developed using the WSDOT standards for streambed sediment and streambed cobble will be more coarse than existing material. In order to match the existing conditions, the existing streambed material will be retained and stockpiled during construction. This native streambed material will then be placed as a 2-foot overlay along the constructed streambed.

Below the 2-foot top layer there will be a 4-foot layer of coarser sediment that will be intermixed with woody material. The coarse material will consist of 60 percent 4-inch cobbles (SS 9-03.11(2)) and 40 percent streambed sediment (SS 9-03.11(1)). The distribution of this material is shown in Table 9. One-foot lifts of the coarser sediment will be installed with woody material above and below each lift to reduce scour. The woody material will consist of small logs (less than 4 inches in diameter), branches and slash, and small pieces blended into the gravel material.

The proposed design also incorporates meander bars. Standard meander bar designs were not used for this site due to the impact of the Chehalis backwater. Instead, a two-way meander bar design, shown in Appendix C, was developed in collaboration with the comanagers. One-man boulders (SS 9-03.11(3)) will be buried within the 4-foot layer of coarse material and backfilled with coarse streambed material to resist extreme Chehalis River scour events. Coarse streambed material will also be placed within the 2-foot fine material layer to provide meander bars at the surface for normal flows.

Bed stability was assessed using the modified shields equation from Appendix E of the USFS Stream Simulation manual (USDA 2008). The average shear stress used to determine stability was extracted from the model time step that had the maximum shear stress through the structure. Further details about the maximum shear stress are found in Section 5. The D_{50} and D_{84} of the coarse sediment buried below the native streambed material is mobile during all flood events except the 2-year UNT to Wenzel Slough flow. However, these calculations do not account for the effect of the woody material that will integrated into the bed matrix. The one-man boulders buried within the meander bars are not mobile under any flood events. The stability of the native stream material cannot be evaluated as pebble counts were not completed, as discussed in Section 2.7.3.

The proposed bed material is expected to support fish passage and habitat. Though fish are not expected to spawn in the tributary, the coarser sediment will improve water quality and oxygen levels in the water, benefiting all fish present.

Table 9: Comparison of observed and proposed streambed material

Sediment size	Observed diameter for design (in)	Proposed coarse streambed material diameter (in)	Proposed meander bar material diameter (in)
D_{16}	NA	0.32	0.94
D_{50}	NA	1.41	14.0
D_{84}	NA	2.78	16.7
D_{95}	NA	3.58	17.6
D_{100}	NA	4.00	18.0

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for UNT to Wenzel Slough at US 12 MP 17.56.

4.3.2.1 Design Concept

Channel complexity features for the US 12 crossing are designed to provide habitat and allow for natural stream processes. The channel complexity features for this crossing include LWM in restored open-channel areas and meander bars within the proposed structure. These channel-forming features are expected to prevent plane-bed morphology and entrainment against the structure walls, and instead to maintain sufficient depth for fish passage throughout the proposed crossing. Wood will be placed both upstream and downstream of the crossing, but no wood will be placed under the structure with the exception of slash material incorporated into the streambed material as discussed in Section 4.3.1. No mobile wood is proposed for this crossing.

To provide additional fish habitat, the existing channel downstream of the proposed crossing will be retained to provide side-channel habitat. See Section 4.1.2 for discussion of the proposed channel realignment.

LWM consists of logs larger than 20 feet in length and 6 inches or greater in diameter at breast height (DBH), often with rootwads attached. LWM can influence channel morphology, creating beneficial habitat, such as pools, back eddies, side channels, and sinuosity. LWM also helps to retain spawning gravel; provide refuge from predators, high velocities, and adverse thermal conditions; and a food source for insects, which in turn provides nourishment to fish (Fox and Bolton 2007). In addition, LWM can increase the stability of newly constructed channels (Castro and Beavers 2016).

The suggested targets for LWM quantities presented in “A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State” (Fox and Bolton 2007) provide the basis for determining the amount of wood placed within the constructed channel. Calculations in WSDOT’s wood quantity calculation spreadsheet depend upon the total length of reconstructed channel, including reaches internal to structures, and the BFW of the stream channel. All relevant calculations are included in Appendix F.

For a BFW of 12 feet, the minimum key piece of density is 3.35 key pieces per 100 feet. With 349 feet of regrading proposed at this site, the LWM targets are 12 key pieces, 40 total pieces, and a volume of 137.8 cubic yards.

To satisfy the large volume target, the proposed design incorporates buried logs. By burying some pieces, logs can be stacked vertically. This allows a larger volume of wood to fit within the regraded channel and still have most logs engaged within the channel's low flow area. The buried wood also provides anchoring for other pieces by lashing logs together. Buried logs will also inhibit scour along the channel during Chehalis River backwater events and buried logs take longer to decompose than surface logs so they will remain in the system longer.

The proposed design, shown in Figure 16 and Appendix D, incorporates 40 key pieces and 60 total pieces of LWM, which exceed the targets. As discussed in Section 8, slash is proposed within the buried structure. With the approval from the Quinault Indian Nation, the volume of the slash has been included in the total volume of proposed LWM calculation, resulting in a volume of 160.0 cubic yards, which exceeds the recommended volume. To ensure the constructability of the LWM design, three cluster types are proposed, as seen in Appendix D. The different clusters provide variability in habitat enhancement and aesthetics while providing clear plans for the contractor.

LWM is placed for habitat enhancement. The LWM will provide cover for fish seeking refuge in the smaller tributary during large Chehalis River floods. Under the structure, meander bars are proposed to provide bed stability and channel complexity, as seen in Figure 16. The meander bars will increase roughness through the proposed structure, stabilize bank morphology, and ensure that the stream does not develop a plane-bed morphology or become entrained against the structure walls. The low-flow channel will be constructed between the meander bars to facilitate fish passage. Additional channel complexity and a low flow channel are expected to develop around the designed LWM and meander bars over time. No low points, such as pools, have been proposed in the design, so there is no risk of fish stranding within the channel. The overbank areas have been designed with positive slope towards the main channel to prevent risk of fish stranding in the floodplain.

Due to the small size of UNT to Wenzel Slough and its location, this site does not see recreational use for swimming or boating. Potential current and future use for fishing is limited, thus the LWM would be low risk to the recreational users.

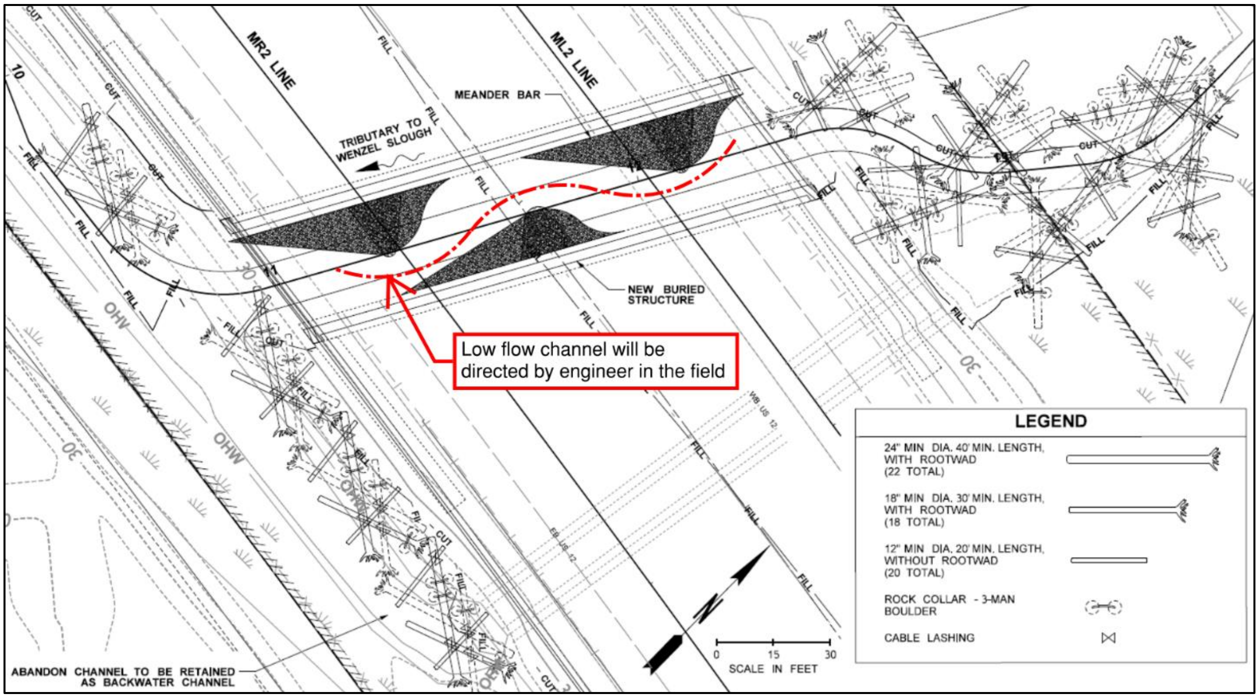

Figure 16: Conceptual layout of habitat complexity

4.3.2.2 Stability Analysis

For simple multi-log structures, large woody material stability analysis is typically completed using the USFS-supplied *Computational Design Tool for Evaluating the Stability of Large Wood Structures* Excel program (Rafferty 2016). The interactions between logs are normally entered into the spreadsheet to determine the stability of each individual log in a structure. However, due to the complexity of the log interactions in the proposed clusters at this crossing, determining the individual stability of logs in a cluster was not feasible. Instead, the stability of the log cluster as a whole was determined. To do so, the USFS-supplied Excel program was used to determine the vertical and horizontal forces acting on each individual log, without accounting for interactions between logs. The forces occurring on individual logs were then summed to determine the total force occurring on the entire log cluster. This is a valid approach because all logs in a cluster are lashed together, and therefore forces on a given log act on the whole cluster.

The stability analysis was completed using the hydraulic modelling results from the 2-year UNT to Wenzel Slough with backwater from the 100-Year Chehalis flood. All calculations are included in Appendix F, and a summary of the stability of individual logs and entire clusters is shown in Table 10. The USFS-supplied tool's assumptions include:

- Flows are not highly turbulent
- Stable and uniform stream geometry
- No debris flows
- Relatively low energy stream that transports sediment smaller than cobbles
- Simple log geometry (e.g., no branches, no partial rootwads)

The LWM clusters require anchoring to be stable during the large Chehalis backwater events. Anchoring details are included in Appendix D.

Table 10: Summary of log ballast requirements

Cluster Type	Log (ID number)	Diameter (in)	Length (ft)	Vertical Force Balance (lbf)	Horizontal Force Balance (lbf)	Anchor requirements	
						Required ballast	Number of rock collars (three-man)
A	1	18	30	1,824	134	N/A	N/A
	2	24	40	129	265	YES	2
	3	24	40	-4,646	-20,737	YES	1
	4	24	40	-22,408	-82,204	N/A	N/A
	5	12	20	453	2	N/A	N/A
	6	12	20	459	58	N/A	N/A
	Cluster Total	-	-	-1,781	-20,279	-	-
B	1	18	30	1,824	188	N/A	N/A
	2	24	40	-2,016	-1,371	YES	3
	3	18	30	-1,694	-4,782	YES	1
	4	24	40	-17,362	-65,655	N/A	N/A
	5	12	20	454	11	N/A	N/A
	6	12	20	454	44	N/A	N/A
	Cluster Total	-	-	-977	-5,909	-	-
C	1	24	40	72	170	YES	2
	2	18	30	-301	-200	YES	1
	3	18	30	-1,960	-8,628	YES	1
	4	24	40	-11,502	-46,537	N/A	N/A
	5	12	20	457	60	N/A	N/A
	6	12	20	458	68	N/A	N/A
	Cluster Total	-	-	-1,275	-8,530	-	-

a. Assumes boulders with submerged specific gravity of 1.65.
b. Negative value indicates anchor and overburden moments exceed buoyant moments.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed US 12 UNT to Wenzel Slough crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.2 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.14 (Aquaveo 2021).

Two scenarios were analyzed for determining stream characteristics for UNT to Wenzel Slough with the SRH-2D models: (1) existing conditions with the existing twin 54-inch-diameter, 143-foot-long culverts and (2) proposed conditions with the proposed 26-foot-wide, 137-foot-long buried bridge structure.

To determine the hydraulic characteristics at the US 12 UNT to Wenzel Slough crossing, the 2-, 100-, 500-, and 2080 projected 100-year storm events were modelled. To demonstrate the hydraulic conditions due to backwater from the Chehalis River, the model incorporates an additional scenario for the existing and proposed conditions occurring at the US 12 UNT to Wenzel Slough crossing. This scenario includes flow from the 2-year storm event in Newman Creek and the UNT to Wenzel Slough and backwater from the 100-year Chehalis flood.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by both WSDOT and 1 Alliance Geomatics, LLC in August 2019, and DEA in March 2020. The survey data were supplemented with 2012 Grays Harbor County light detection and ranging (LiDAR) data (Grays Harbor 2012). Proposed channel geometry was developed from the proposed grading surface created by the DEA design team. Topographic surface development for proposed conditions site geometry was done using InRoads v8i. Section 4.1 provides further detail regarding the proposed channel grading. All survey and LiDAR information is referenced against the NAVD88 datum.

To account for the fact that LiDAR data does not include bathymetry, a representative channel cross section was stamped into the LiDAR upstream of the survey at a slope of 0.3 percent (3 x 10-3 foot/foot) and below US 12 parallel to the highway for 2,300 feet at zero percent slope. Surveyed cross sections both upstream and downstream of the US 12 Newman Creek bridge crossing were used to determine channel geometry for Newman Creek. This geometry was used to stamp a channel for Newman Creek at a 0.2 percent (2 x 10-3 foot/foot) slope.

5.1.2 Model Extent and Computational Mesh

To ensure the upstream model boundary did not affect the hydraulics at the crossing, the model domain was defined by the 35-foot contour and delineated approximately 1,600 linear feet north of the US 12 crossing. The mesh also includes an approximate 3,800-foot-long section of

Newman Creek to the west of UNT to Wenzel Slough, as the floodplain between these creeks converge during peak flood events. The downstream mesh boundary is approximately 1,900 linear feet south of the US 12 crossing.

The existing conditions mesh, shown in Figure 17 and Figure 18, contains 103,310 elements and covers just 1.1 square miles. Both the existing and proposed conditions meshes utilize quadrilateral elements within the main channel and triangular elements over the remaining surface area. The mesh within the channel consists of quadrilateral elements that are approximately 1.5 to 3 feet wide and 3 to 10 feet long. The vertex spacing of mesh elements at the model domain is approximately 100-feet.

The proposed conditions mesh, shown in Figure 19 and Figure 20, contains 106,841 elements and covers the same areal extents as the existing mesh. The element types and sizes are the same as the existing conditions mesh except at the proposed structure where elements within the structure are 1.5 feet wide and 3.5 feet long. The bridge abutments were modelled as holes in the mesh and can be seen Figure 21.

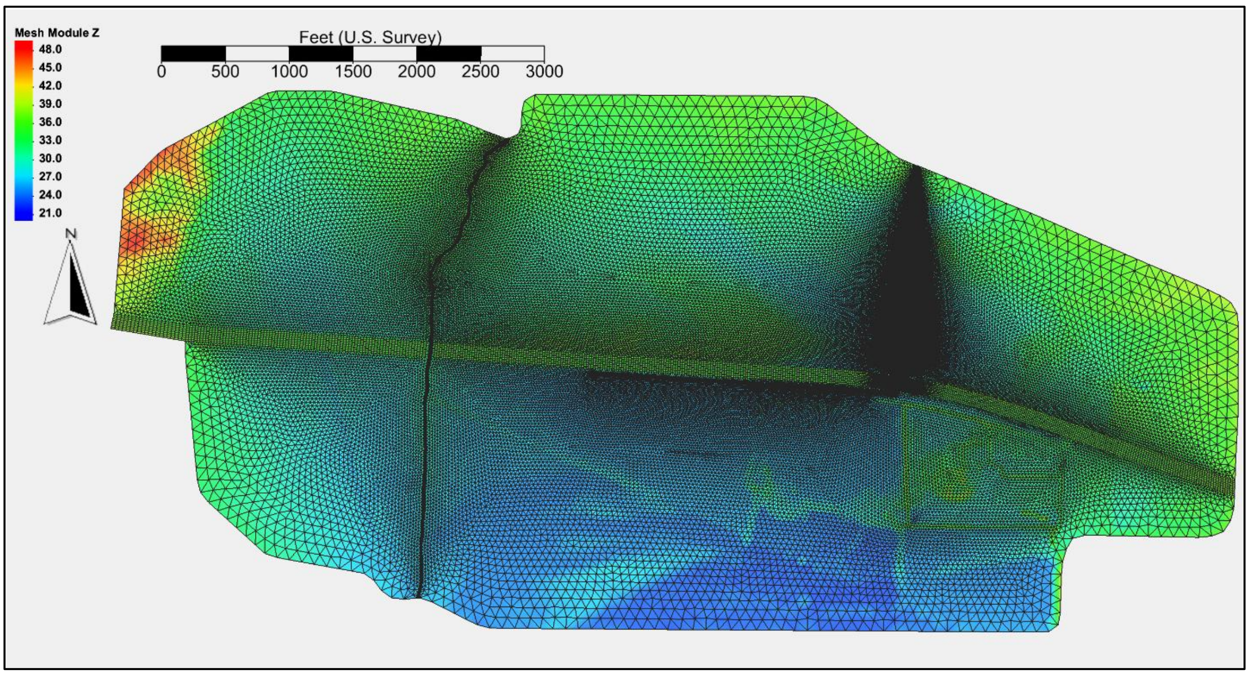

Figure 17: Existing conditions computational mesh with underlying terrain (Newman Creek to the west, UNT to Wenzel Slough to the east)

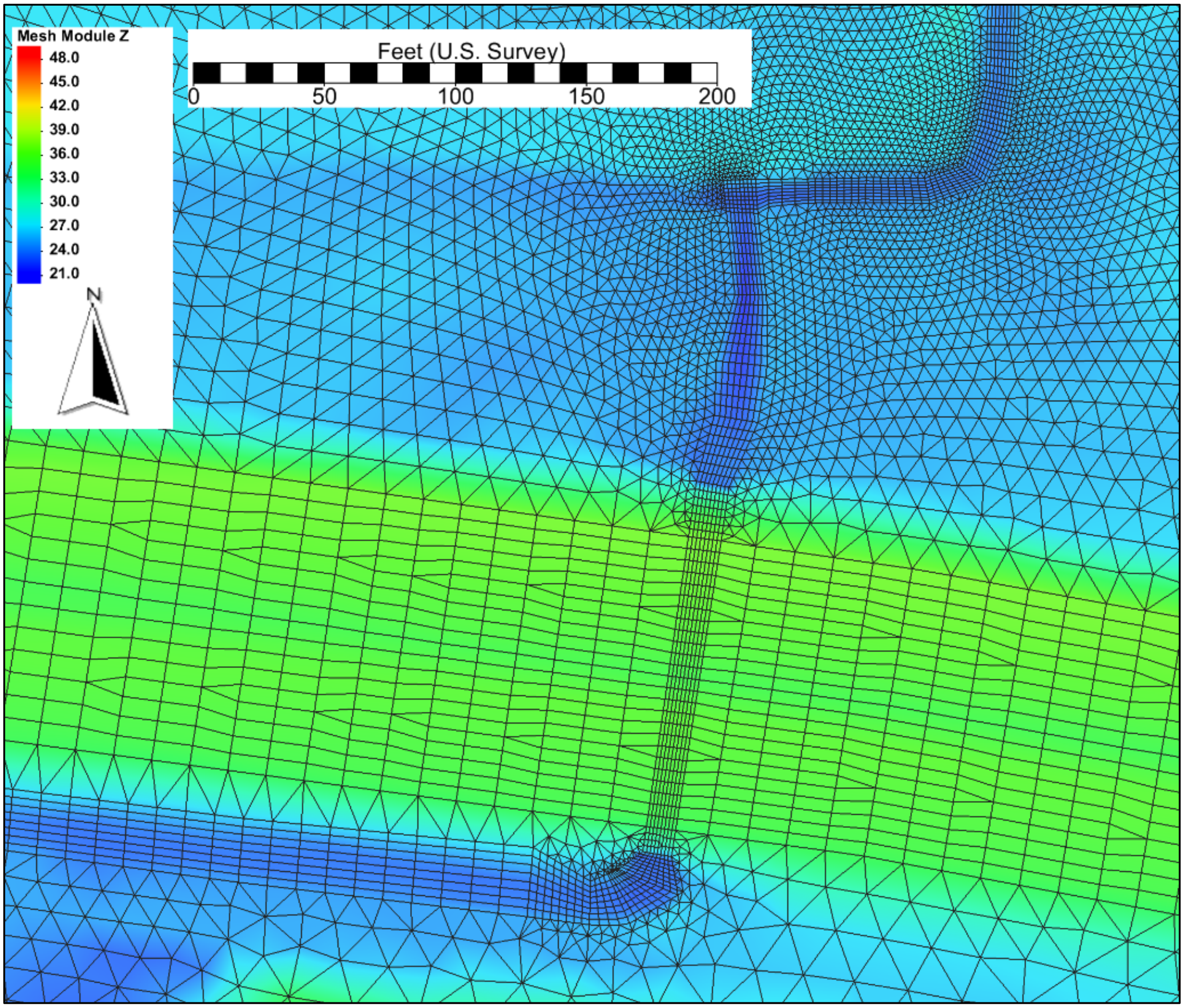

Figure 18: Existing conditions mesh at US 12 crossing of UNT to Wenzel Slough

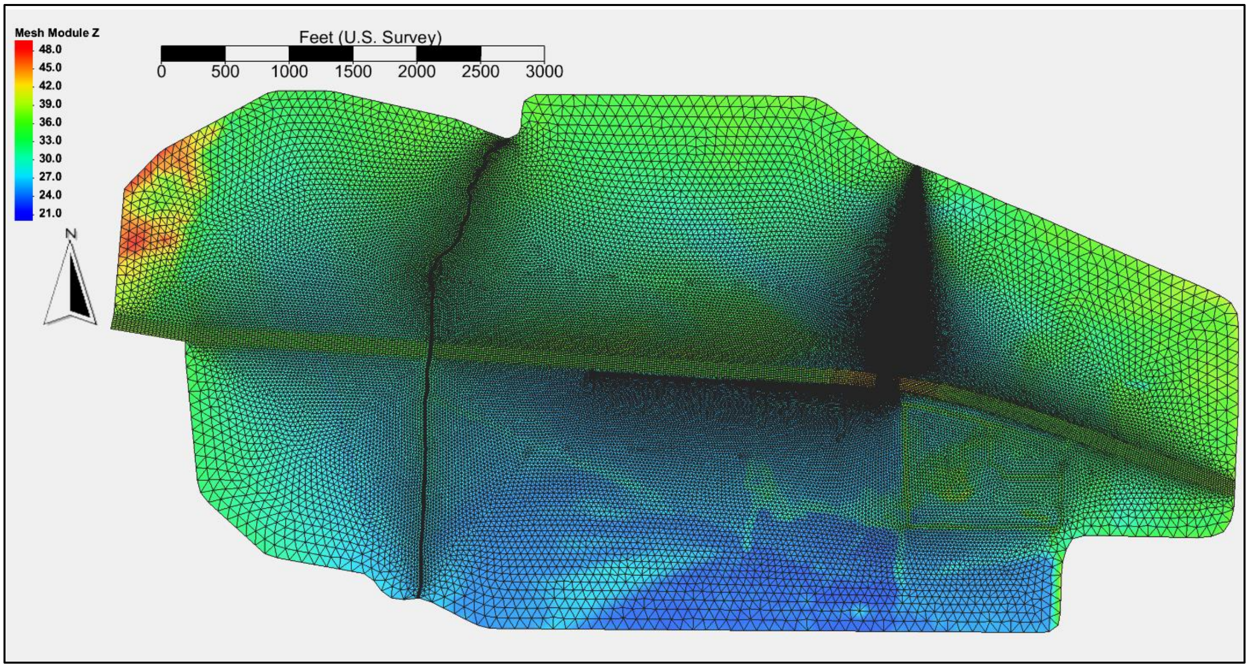

Figure 19: Proposed conditions computational mesh with underlying terrain (Newman Creek to the west, UNT to Wenzel Slough to the east)

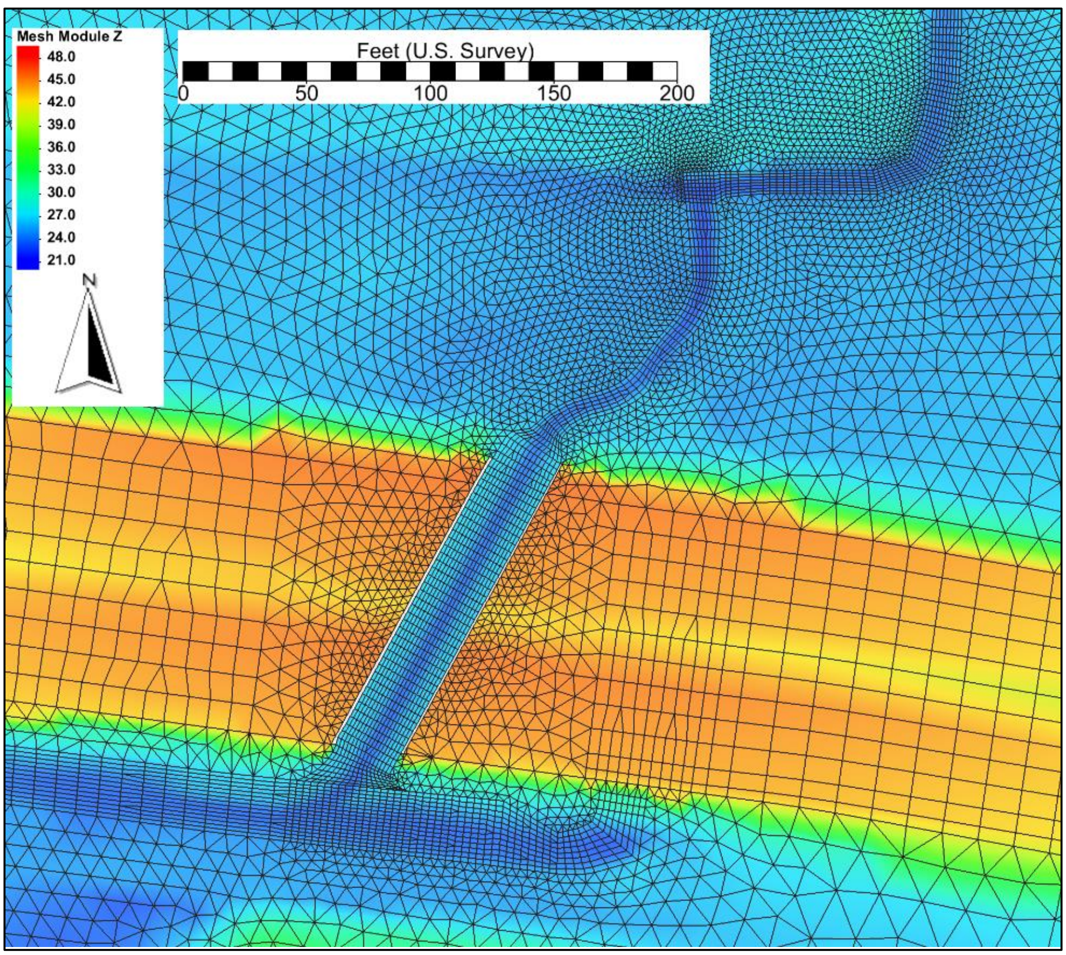

Figure 20: Proposed conditions mesh at US 12 crossing of UNT to Wenzel Slough

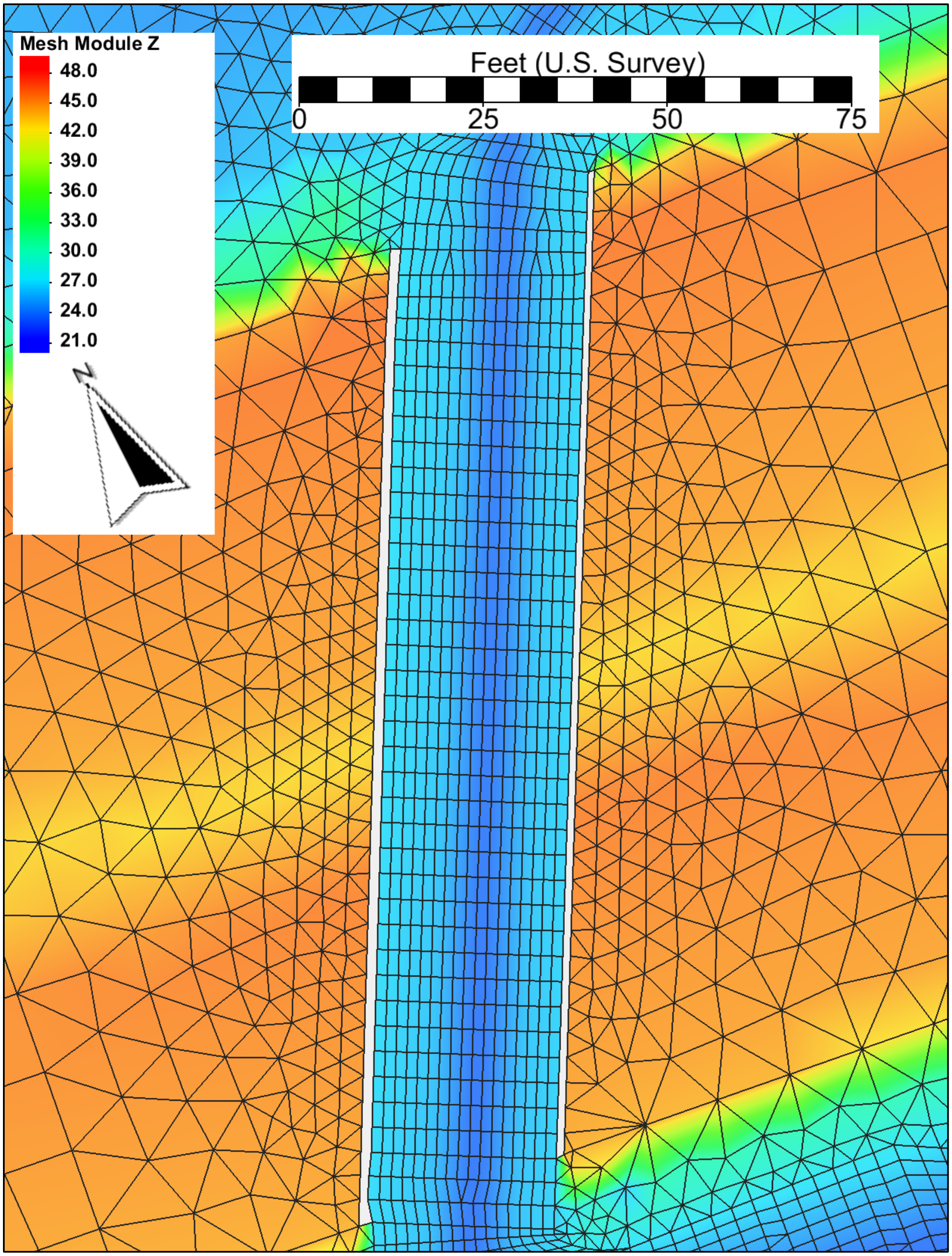

Figure 21: Location of holes in the proposed conditions mesh

5.1.3 Materials/Roughness

Roughness values used in the model are based on commonly cited literature (WSDOT 2019; Chow 1959) as well as field observations, professional judgement, and aerial imagery. Table 11 lists the values selected for both the existing conditions and the proposed conditions. Existing and proposed conditions roughness coverages are the same except within the vicinity of the proposed channel. The proposed channel will include LWM, which will significantly increase the roughness compared to existing conditions. The channel within the proposed structure will not contain any LWM and will have a surface roughness similar to the existing condition.

The roughness coverage for existing conditions is shown in Figure 22. Figure 23 shows a closer view of the UNT to Wenzel Slough crossing of US 12 under existing conditions. Figure 24 shows the Newman Creek crossing of US 12 under both existing and proposed conditions.

For the proposed conditions, roughness values for the proposed channel material and LWM were added to those used in the existing conditions, as seen in Table 11. Similar to existing conditions, roughness values were selected based on typical ranges found within the WHM (2019) and professional judgement. The spatial distribution of these roughness values is seen in Figure 25. The locations of the new materials around the UNT to Wenzel Slough crossing of US 12 are shown in Figure 26.

Table 11: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n	Existing or Proposed Conditions
Existing Channel	0.032	Both
Dense Brush	0.100	Both
Light Brush	0.065	Both
Roadway	0.013	Both
Open Water	0.015	Both
Moderate Riparian Vegetation	0.064	Both
Thick Riparian Vegetation	0.078	Both
Proposed Channel	0.030	Proposed
Large Woody Material (LWM)	0.080	Proposed

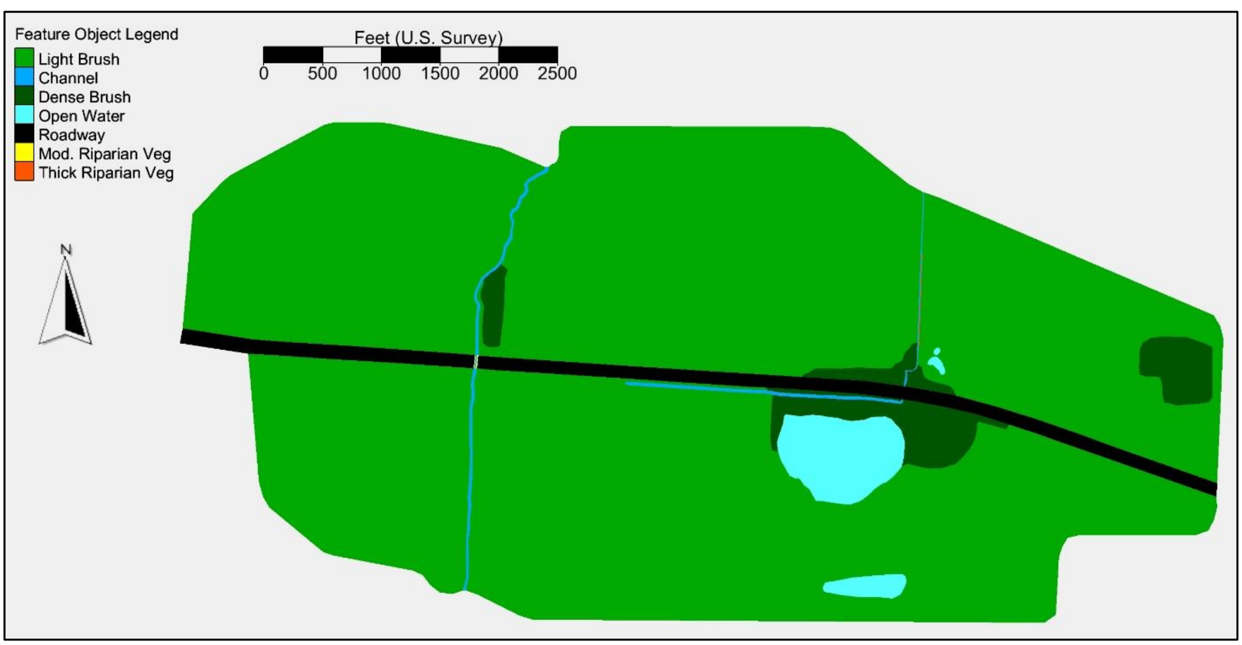

Figure 22: Spatial distribution of existing-conditions roughness values in SRH-2D model

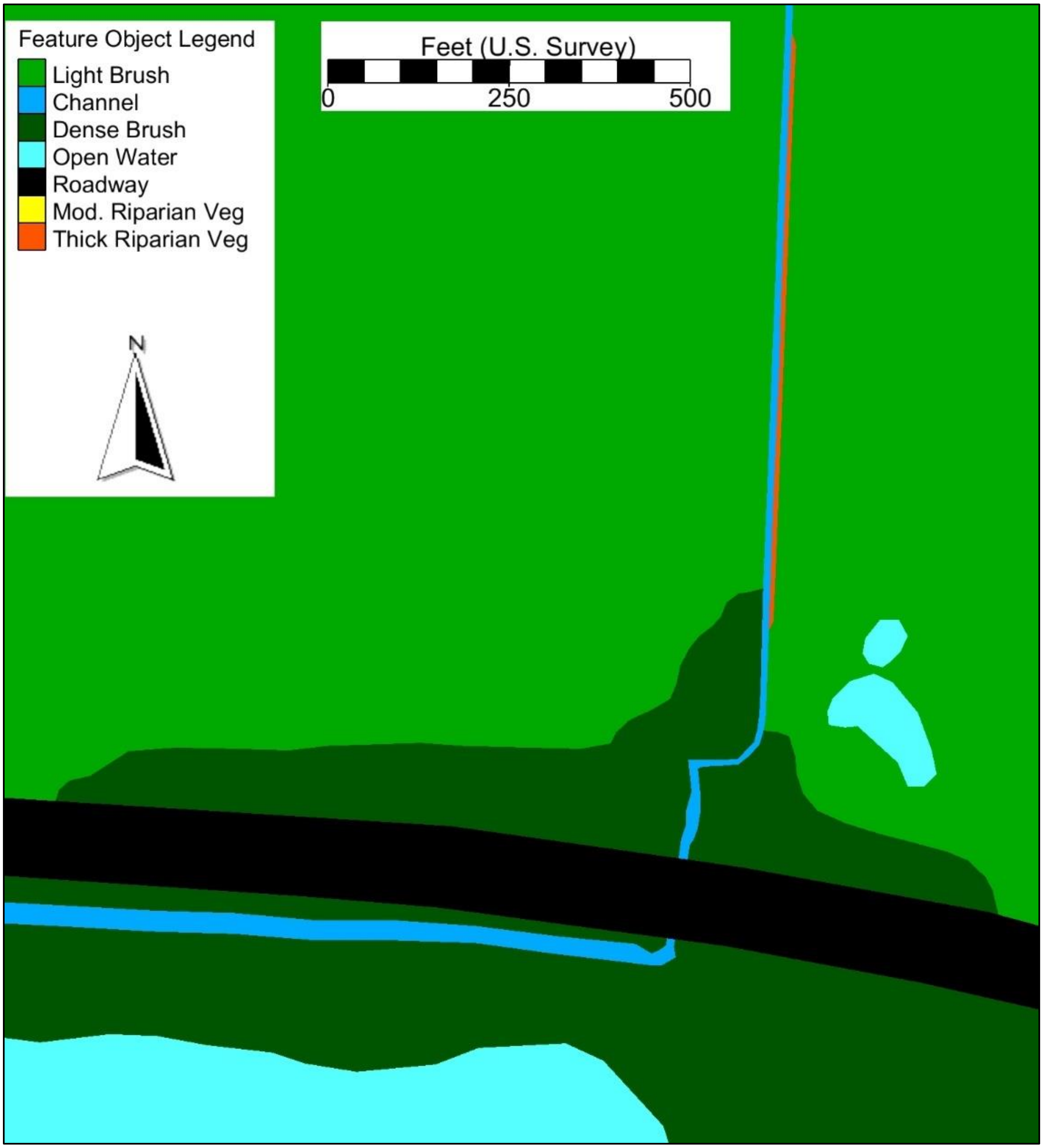

Figure 23: Spatial distribution of existing-conditions roughness values around the UNT to Wenzel Slough US 12 crossing

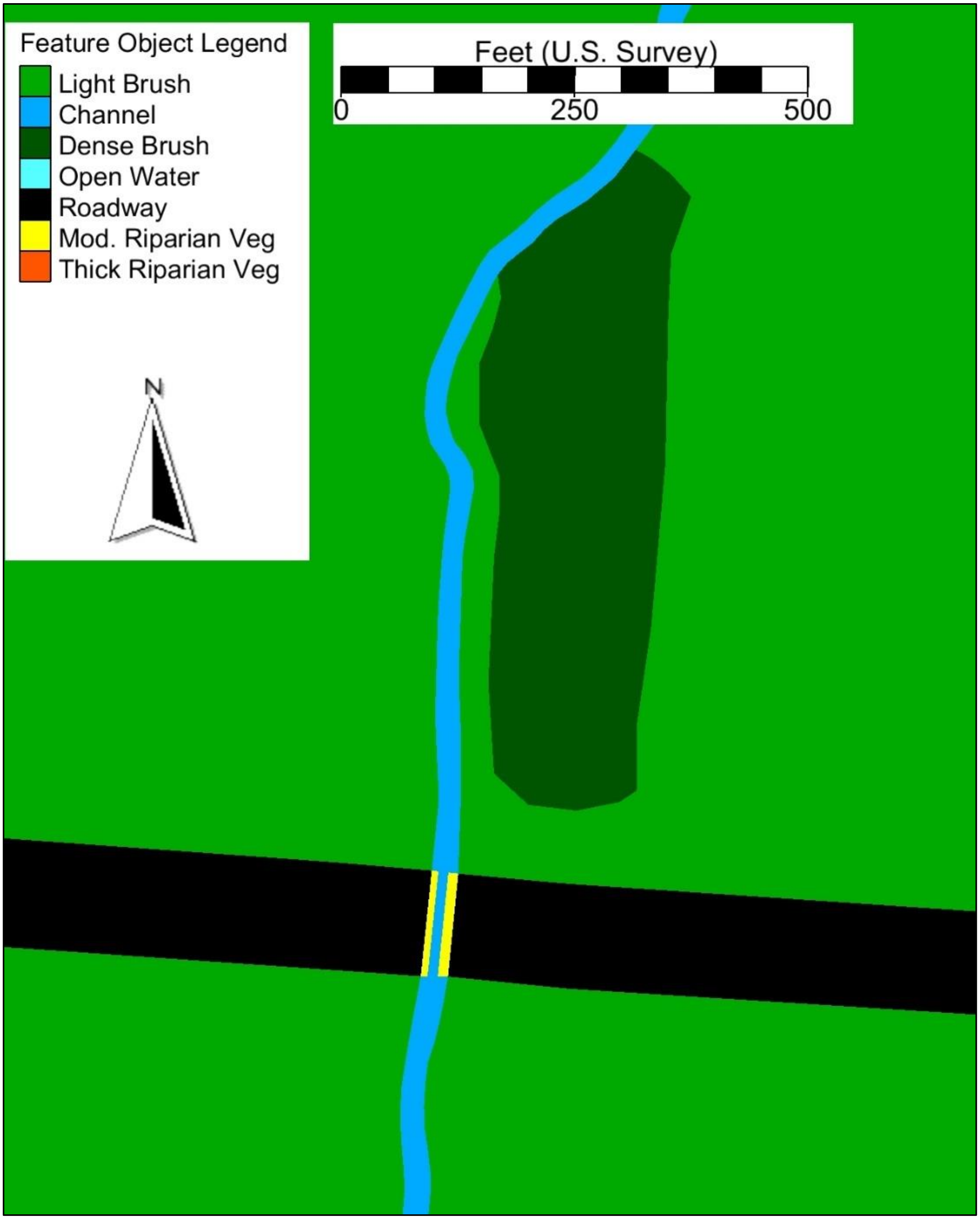

Figure 24: Spatial distribution of existing and proposed conditions roughness values around the Newman Creek US 12 crossing

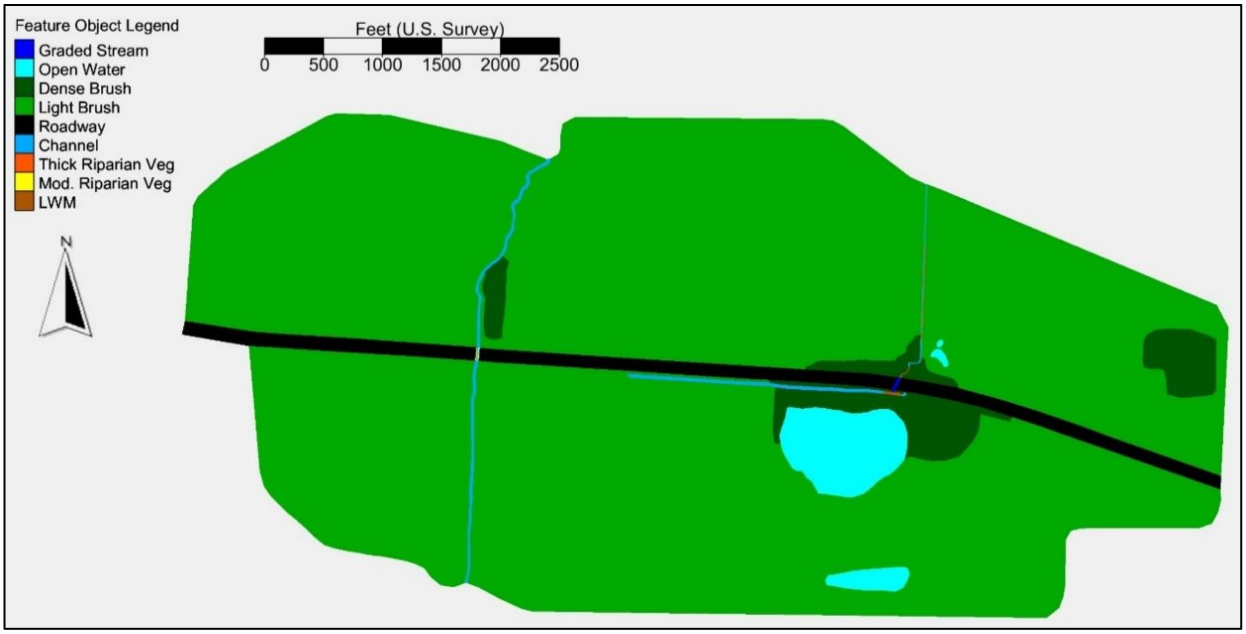

Figure 25: Spatial distribution of proposed-conditions roughness values in SRH-2D model

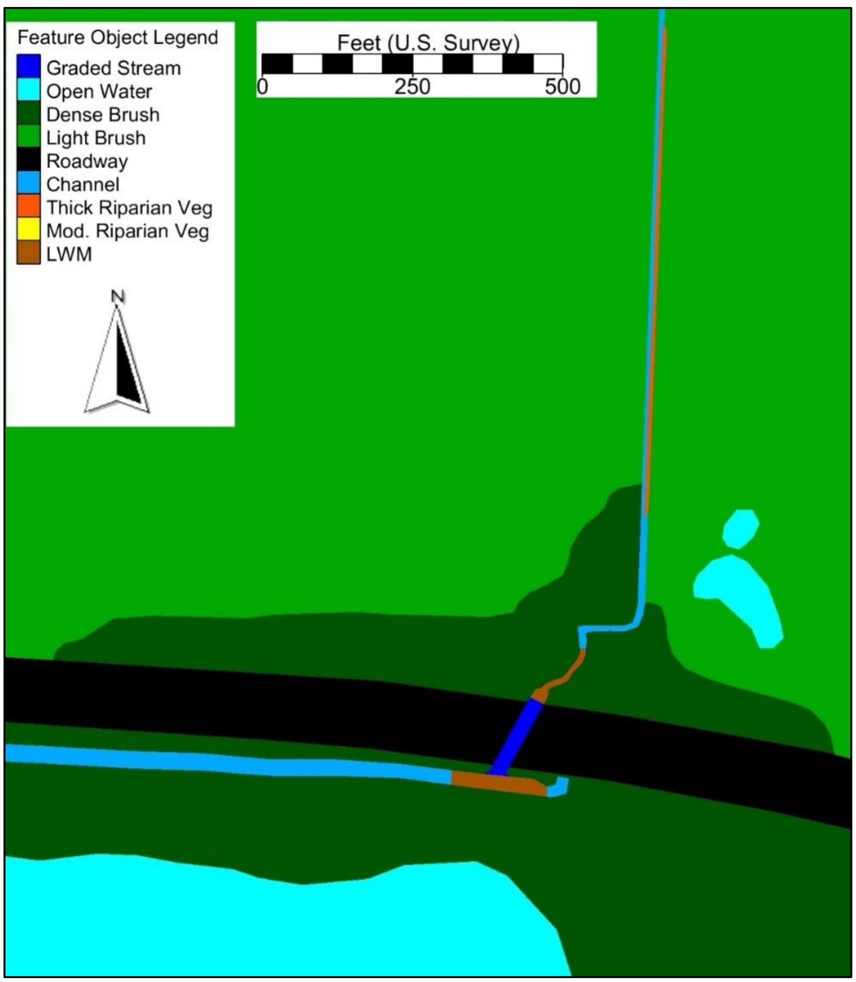

Figure 26: Spatial distribution of proposed-conditions roughness values around the UNT to Wenzel Slough US 12 crossing

5.1.4 Boundary Conditions

The hydraulic model for UNT to Wenzel Slough was run as an unsteady state model. Figure 27 shows the location of the existing boundary conditions and Figure 28 shows the locations of the proposed boundary conditions. The inflow boundary conditions use a hydrograph that was developed from a unit hydrograph (see Figure 29) scaled to the peak flows (see Section 3). The existing culvert was modelled as a 4.5-foot diameter double barrel CMP using the one-dimensional HY-8 model (FHWA Version 7.60) coupled to the SRH-2D model. The HY-8 input parameters for each barrel are shown in Figure 30 and Figure 31. For the simulations where the effects of the Chehalis River were not considered, the downstream boundary condition is a constant water surface elevation. The water surface elevation was determined by a normal depth calculation using the combined flows of Newman Creek and the UNT to Wenzel Slough, with a slope of 0.1 percent and a Manning's n of 0.045. The rating curve for the downstream boundary condition is shown in Figure 32. For simulation where Chehalis backwater was included, the downstream boundary condition is a time-varying water surface elevation that follows the graph shown in Figure 33. The minimum stage is 23.0 feet and the maximum stage is 36.3 feet, which was obtained from independent hydraulic models of the Chehalis River created by others.

For proposed conditions, all boundary conditions remained the same, with the exception of the addition of a no-slip wall boundary condition placed at the location of the bridge abutments.

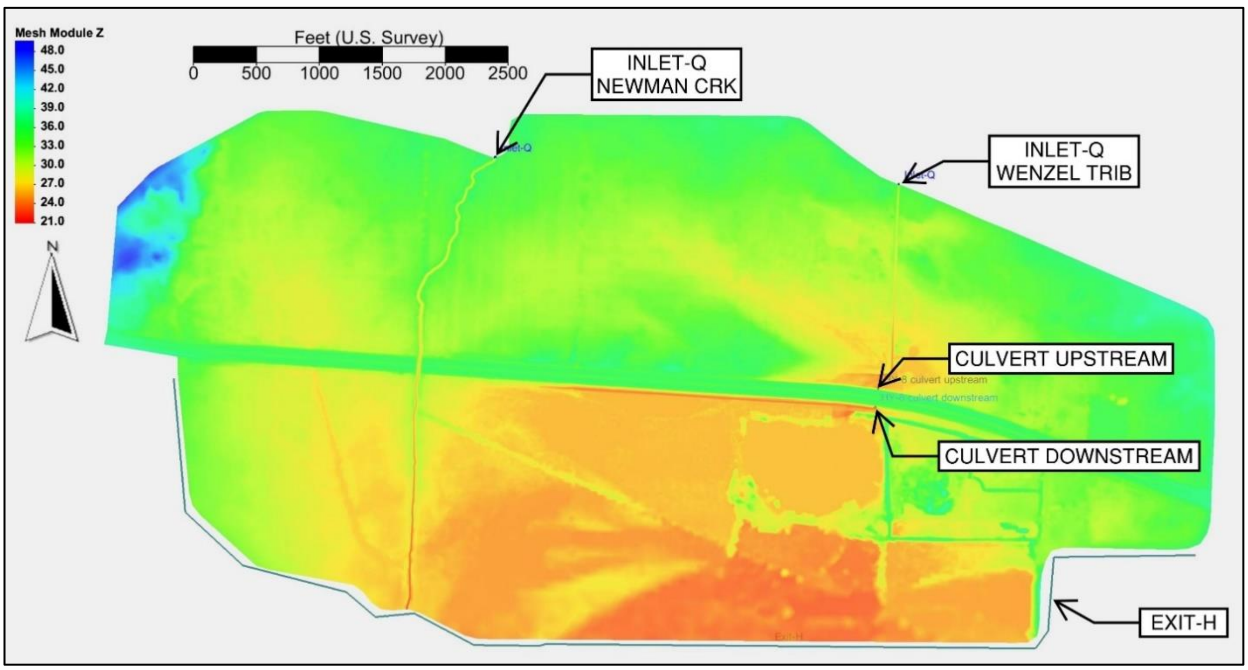

Figure 27: Existing-conditions boundary conditions

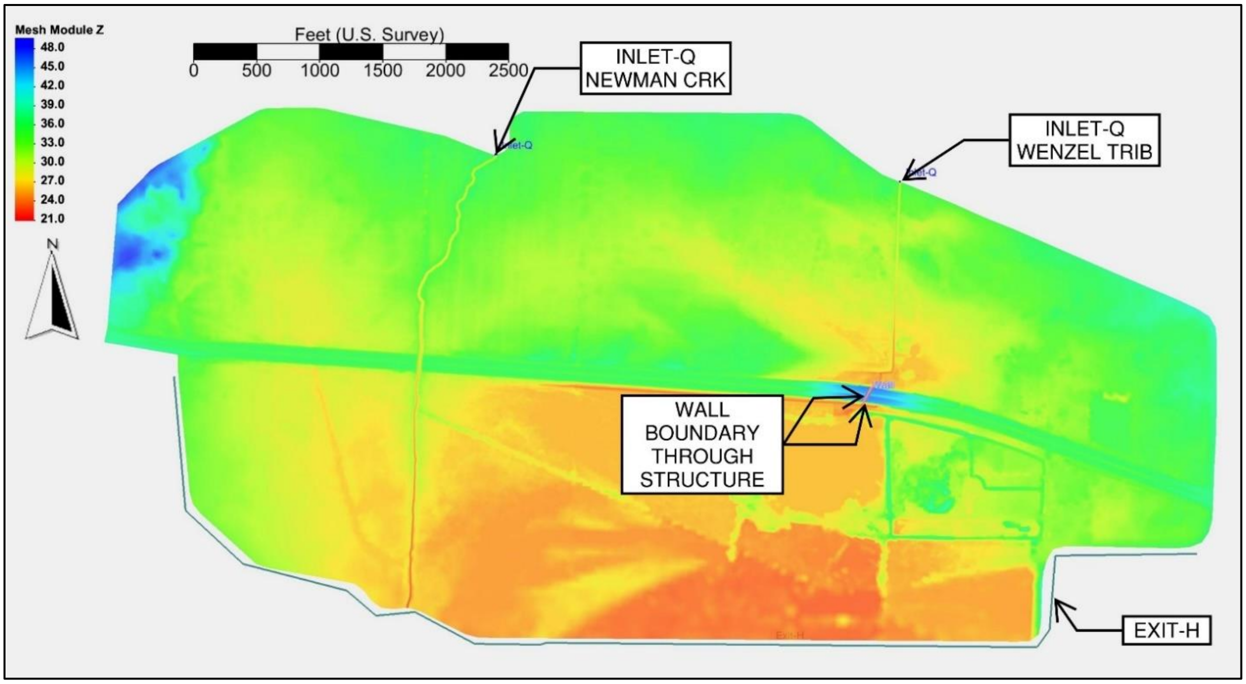

Figure 28: Proposed-conditions boundary conditions

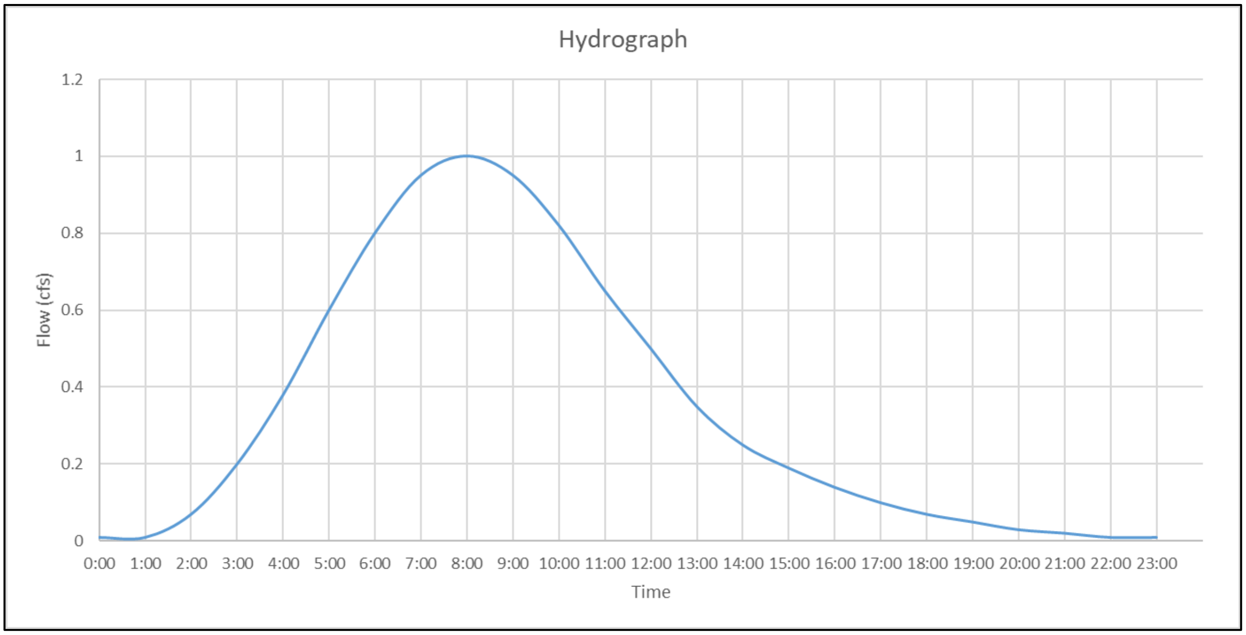

Figure 29: Unit hydrograph

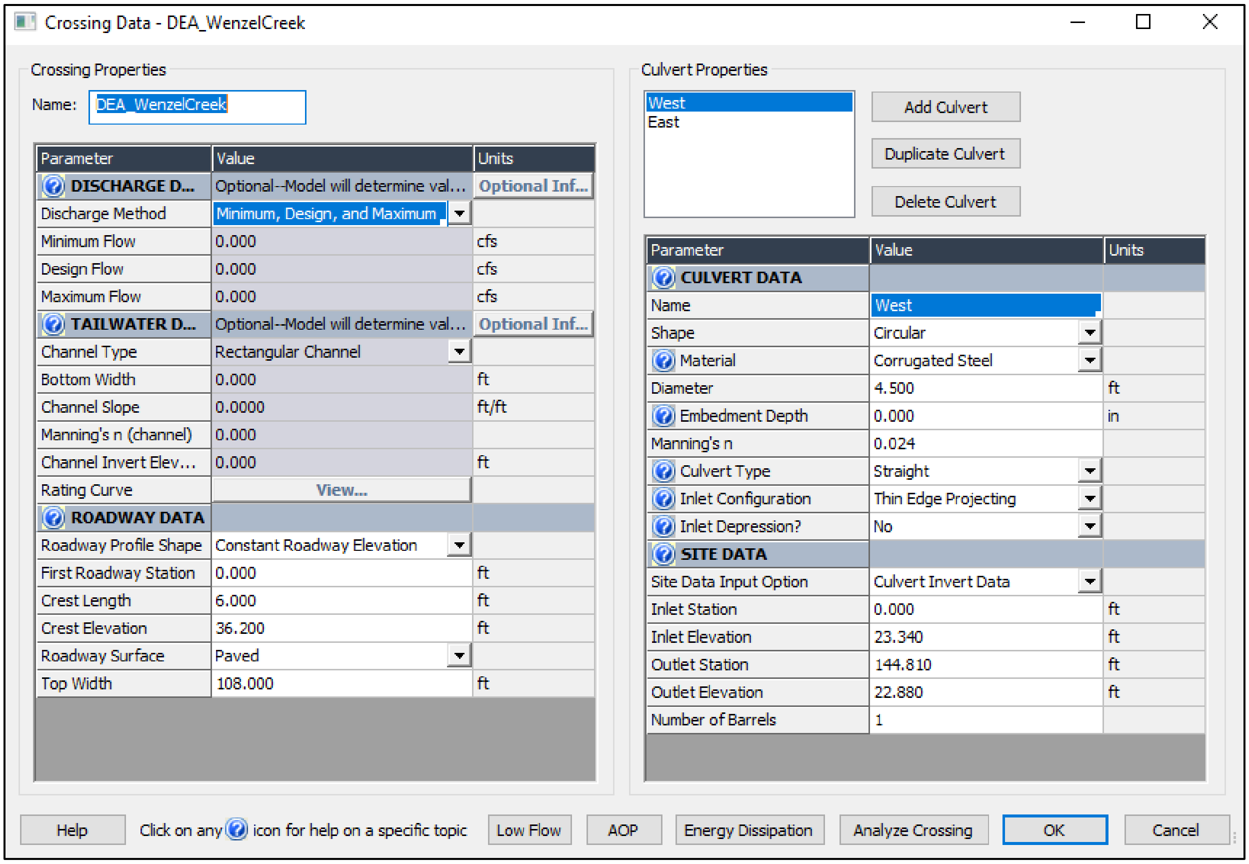

Figure 30: HY-8 culvert parameters for the western barrel

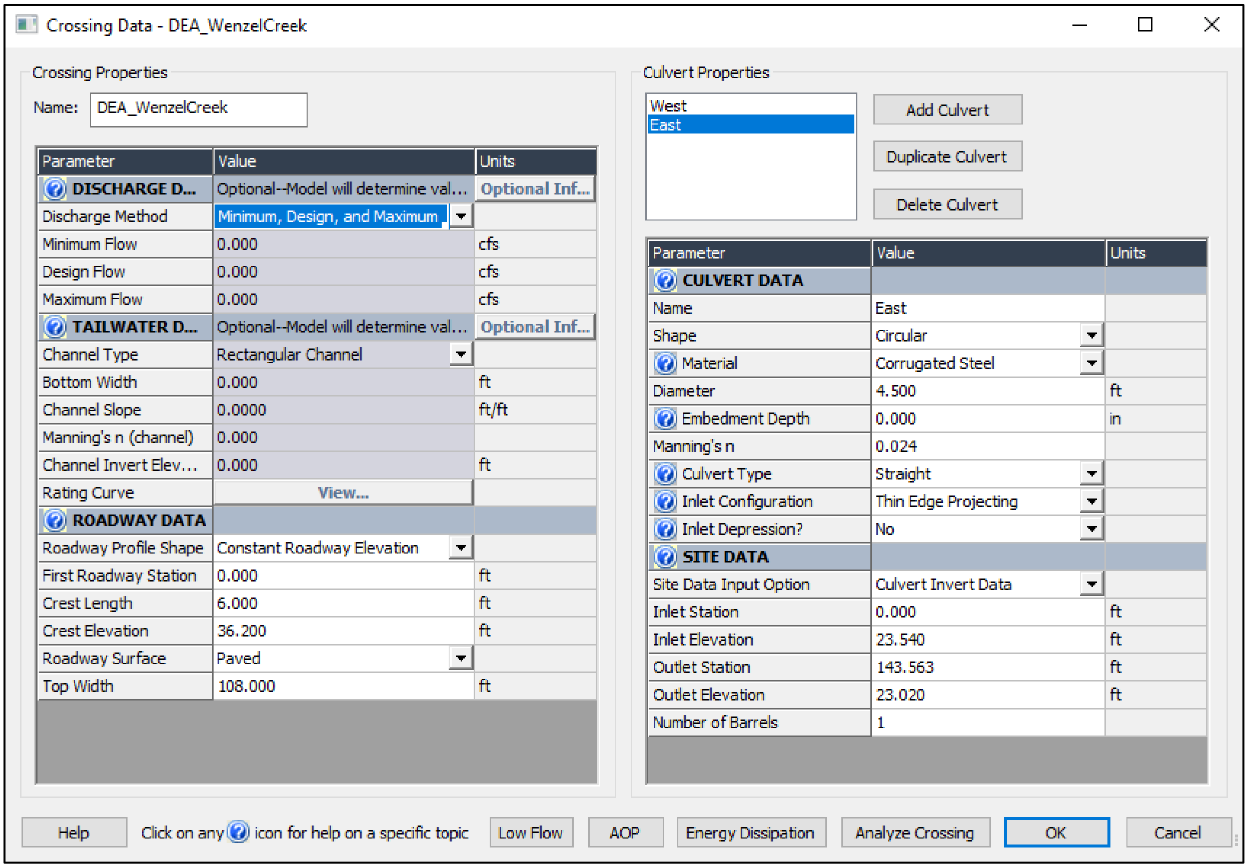

Figure 31: HY-8 culvert parameters for the eastern barrel

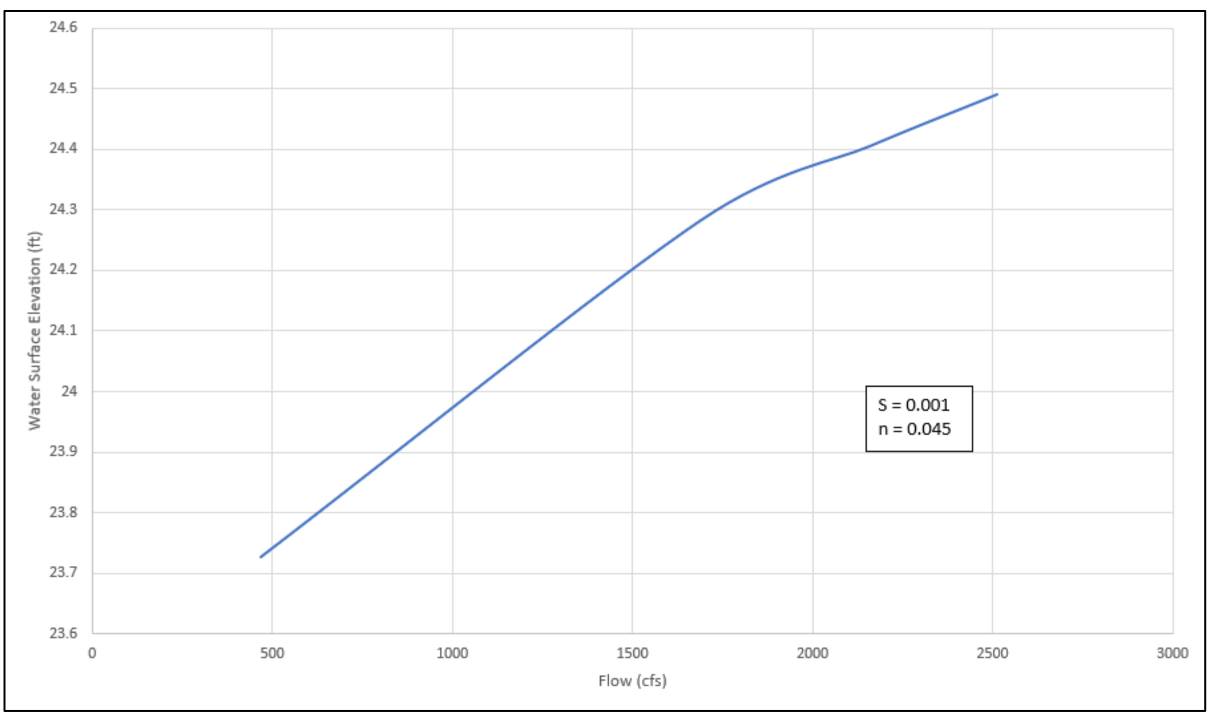

Figure 32: Downstream outflow boundary condition normal depth rating curve

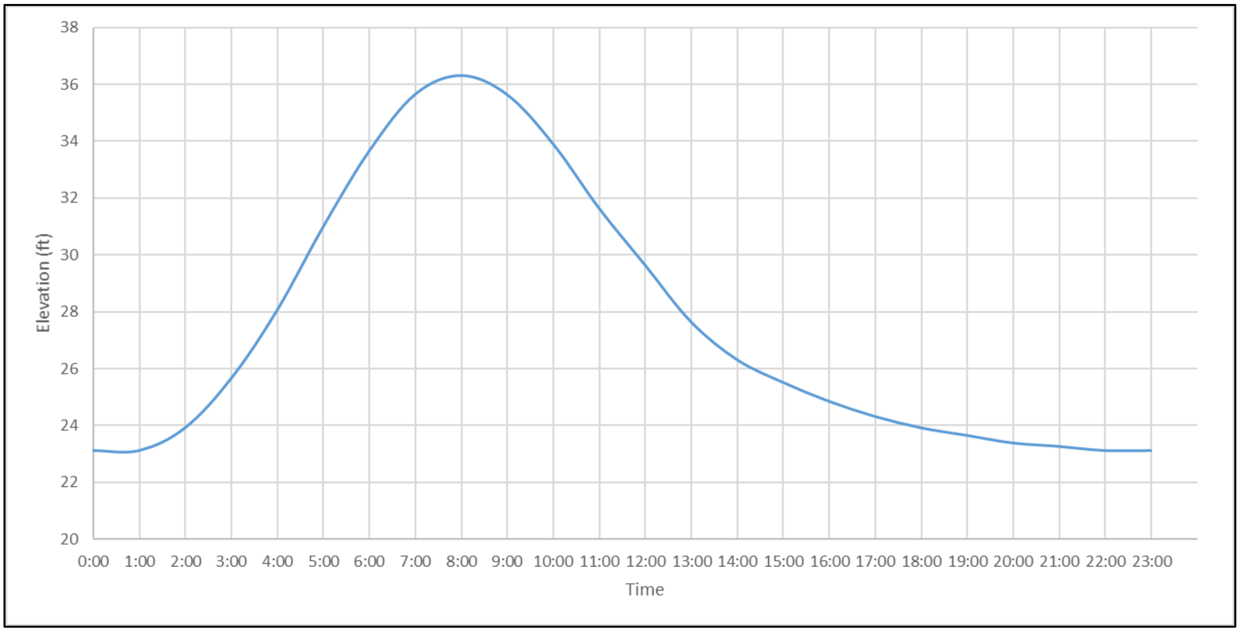

Figure 33: 100-year Chehalis River stage boundary condition

5.1.5 Model Run Controls

The SRH-2D model was run with a dry initial condition starting at 0 hours and ending at 24 hours with a 0.5 second time step. Default turbulence values were used. Because this is an unsteady state model, achieving steady state was not anticipated, however, the model was stable through the run time. See Appendix I for the model stability and continuity plots.

5.1.6 Model Assumptions and Limitations

The time variable inflow and outflow boundary conditions were approximated based upon general trends observed in flood stage curves. Both the duration of the events and the timing of the peaks are approximate. The inflow boundary conditions for both Newman Creek and the UNT to Wenzel Slough reaches the peak flow 8 hours after the simulation began, as they each follow the hydrograph shown in Figure 29. The downstream boundary condition representing the 100-year flood in the Chehalis backwater reaches peak stage at 8 hours and assumes that the water surface elevation of the Chehalis River is constant across the downstream boundary condition.

The hydraulic model is limited in its depiction of the Chehalis 100-year flood. Despite the mesh being over a square mile in size, it only includes two of the many US 12 crossings within the Chehalis 100-year floodplain. In addition to the US 12 crossings, the Chehalis floodwaters can reach the north side of US 12 in overbank flow from the Satsop River or by flowing over low points in US 12 west of the UNT to Wenzel crossing. For this reason, the hydraulic model does not accurately depict the full hydraulics of the Chehalis floodplain.

Because the proposed design shifts the channel alignment from its current position, different stationing is used across existing and proposed conditions to report results. The existing conditions alignment is shown in Figure 34 and the proposed alignment is shown in Figure 35.

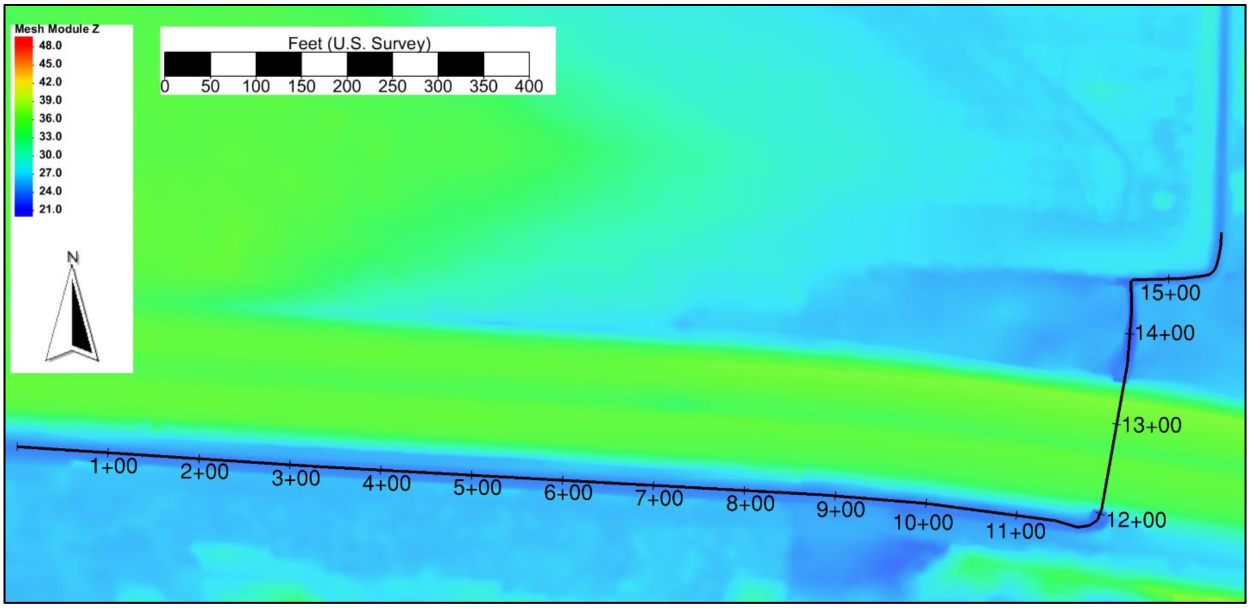

Figure 34: Existing conditions stationing

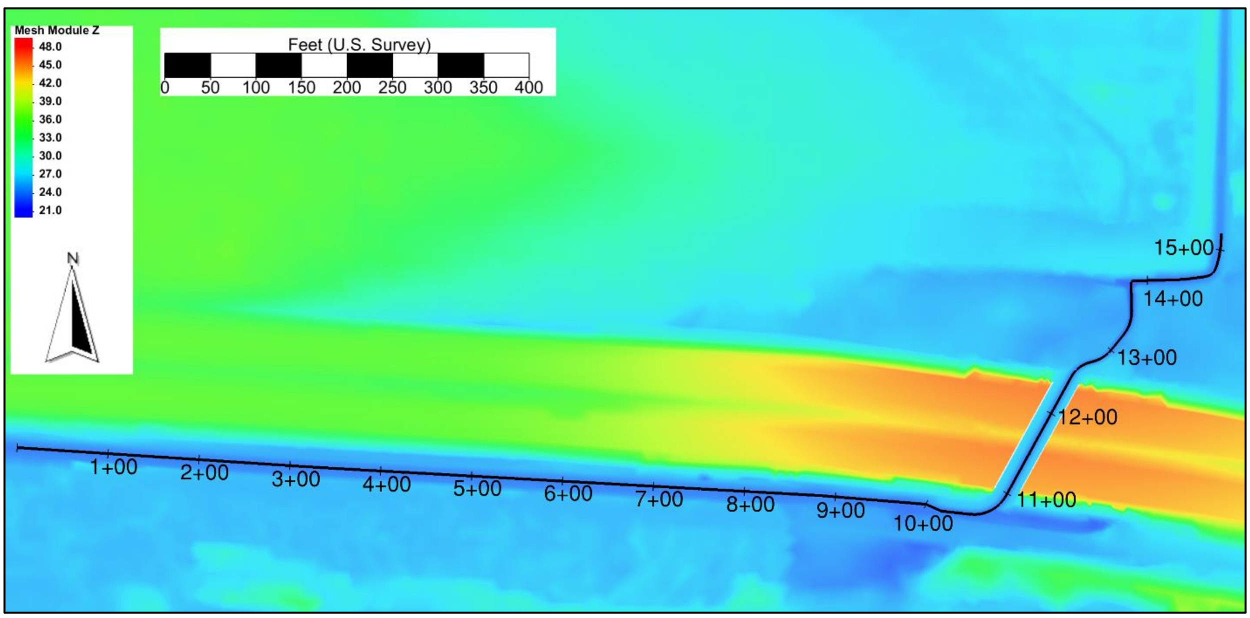

Figure 35: Proposed conditions stationing

5.2 Existing Conditions

Because the hydraulic model was modelled as an unsteady state simulation, data in the following figures and tables have been extracted 8 hours into the simulation when the inflows and, if applicable, Chehalis stage, are at their maximum, as explained in Section 5.1.4.

In addition to the data extracted at the 8-hour time step, values for the peak WSE, shear stress, and velocity occurring at various other time steps are discussed as well since these values are important to evaluate the design. Time steps are referred as times since the beginning of the hydraulic simulation. For example, a time of 14:30 refers to the results 14 hours and 30 minutes into the 24-hour simulation.

Newman Creek contributes significantly to the tributary during the 100-, 500-, and 2080 projected 100-year flows under existing conditions. Figure 36 shows the cross section used to evaluate flow between Newman Creek and the tributary and Figure 37 shows the flow over time. Positive values on Figure 37 indicate flow from Newman Creek to the tributary and negative flows indicate the opposite. At the peak, Newman Creek contributed flows equivalent to UNT to Wenzel's peak flows determined in Section 3.

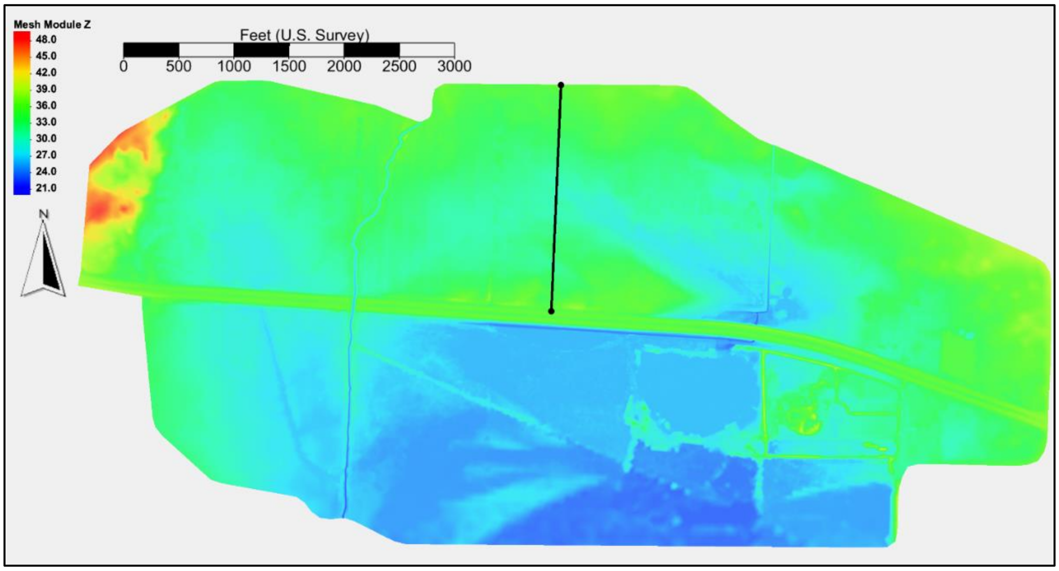

Figure 36: Location of cross section to determine flow between Newman Creek and UNT to Wenzel

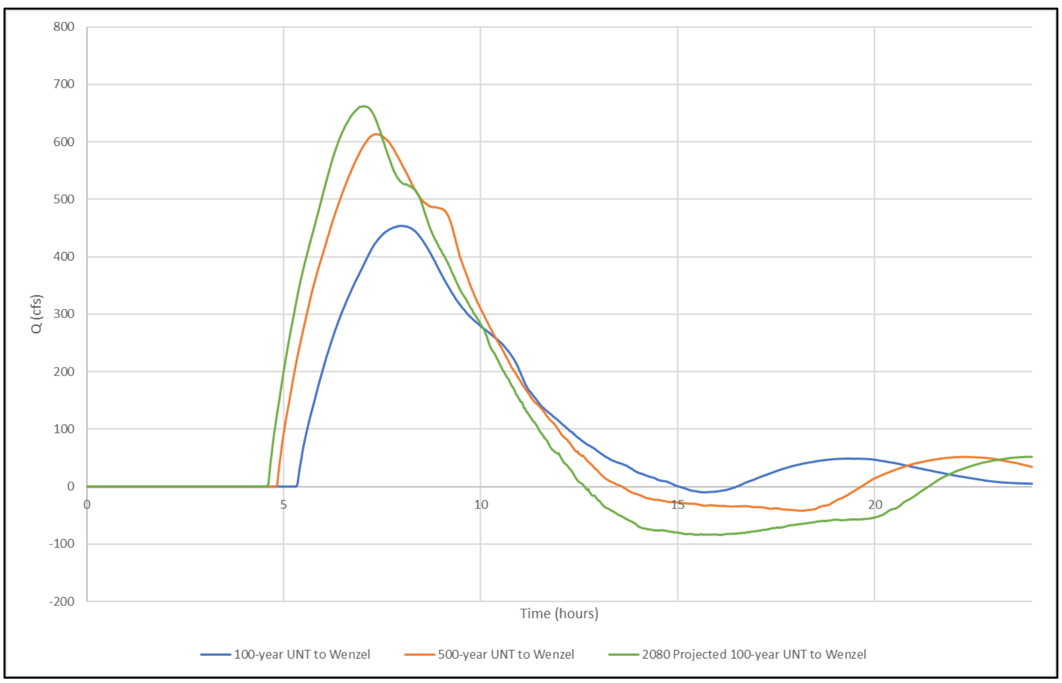

Figure 37: Existing conditions flow between Newman Creek and UNT to Wenzel

Figure 38 shows the locations of cross sections used in Table 12. As seen in Figure 39, the existing culvert backwaters upstream of US 12, on the north side, during every flood event. This is seen further by comparing the large differences in WSE at upstream and downstream cross sections as shown in Figure 40 and Figure 41. The culvert inlet becomes fully submerged during all flood events. For the scenario when there is 2-year flow at the UNT to Wenzel and 100-year flow in the Chehalis River, flood water from the Chehalis River backwaters against the south side of US 12 and overtops the highway, as seen in Figure 39.

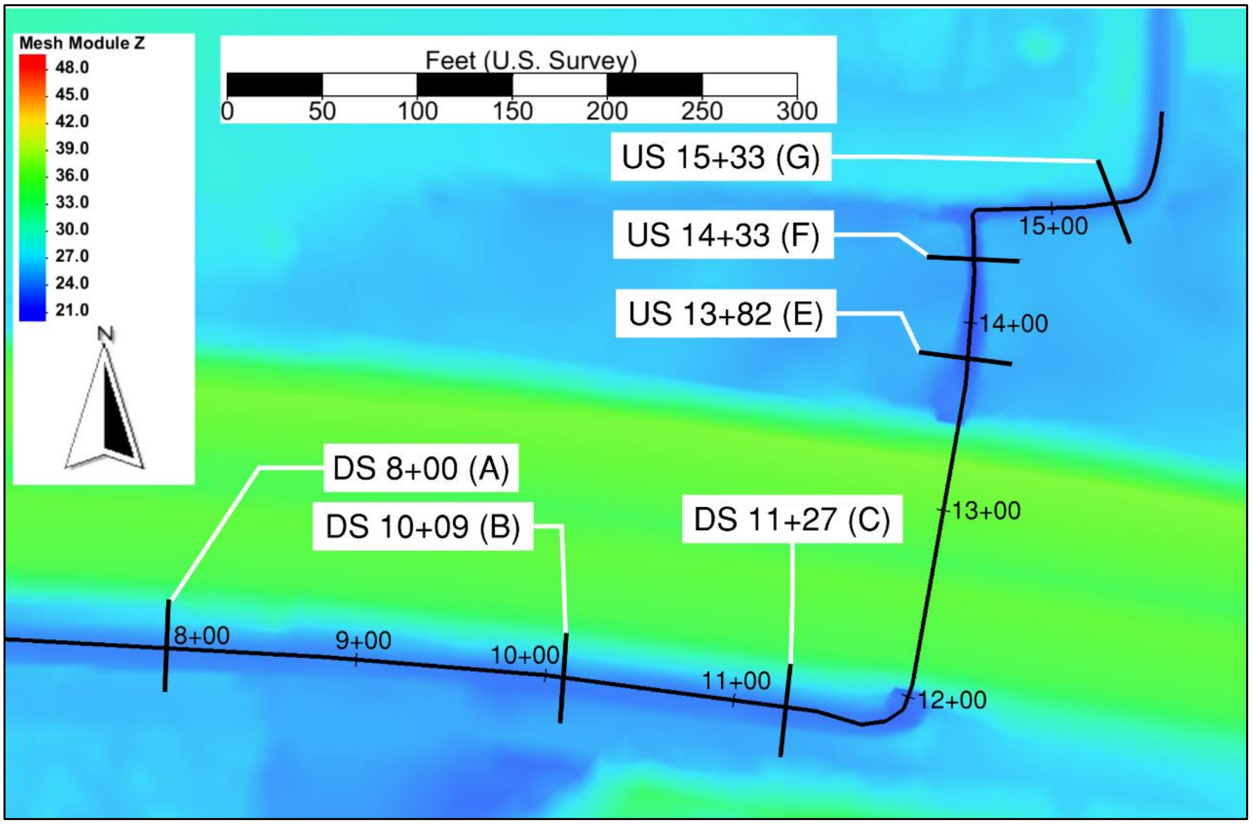

Figure 38: Locations of cross sections used for results reporting

Table 12: Average main channel hydraulic results for existing conditions at 8:00

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS 8+00 (A)	26.3	26.9	27.0
	DS 10+09 (B)	26.3	27.0	27.1
	DS 11+27 (C)	26.4	27.1	27.2
	Structure (D)	NA	NA	NA
	US 13+82 (E)	27.0	31.1	32.1
	US 14+33 (F)	27.0	31.1	32.1
	US 15+33 (G)	27.0	31.1	32.1
Max depth (ft)	DS 8+00 (A)	2.7	3.3	3.4
	DS 10+09 (B)	3.1	3.7	3.8
	DS 11+27 (C)	3.1	3.8	3.9
	Structure (D)	NA	NA	NA
	US 13+82 (E)	4.6	8.8	9.7
	US 14+33 (F)	5.0	9.1	10.1
	US 15+33 (G)	3.3	7.5	8.4
Average velocity (ft/s)	DS 8+00 (A)	0.8	1.4	1.4
	DS 10+09 (B)	1.0	2.4	2.6
	DS 11+27 (C)	0.9	2.1	2.2
	Structure (D)	NA	NA	NA
	US 13+82 (E)	0.5	0.4	0.4
	US 14+33 (F)	0.2	0.2	0.2
	US 15+33 (G)	0.8	0.1	0.1
Average shear (lb/SF)	DS 8+00 (A)	0.0	0.1	0.1
	DS 10+09 (B)	0.0	0.2	0.2
	DS 11+27 (C)	0.0	0.2	0.3
	Structure (D)	NA	NA	NA
	US 13+82 (E)	0.0	0.0	0.0
	US 14+33 (F)	0.0	0.0	0.0
	US 15+33 (G)	0.1	0.0	0.0

Main channel extents were approximated by inspection of channel banks in the topography.

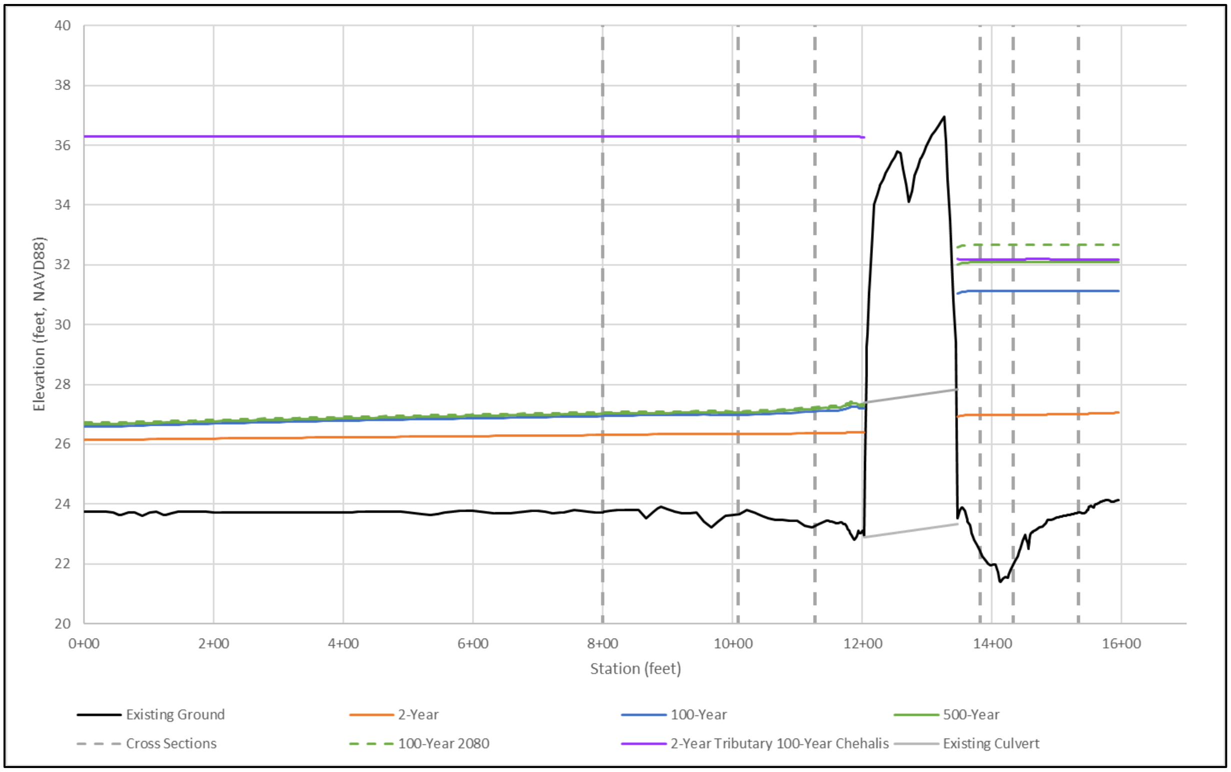

Figure 39: Existing conditions water surface profiles at 8:00

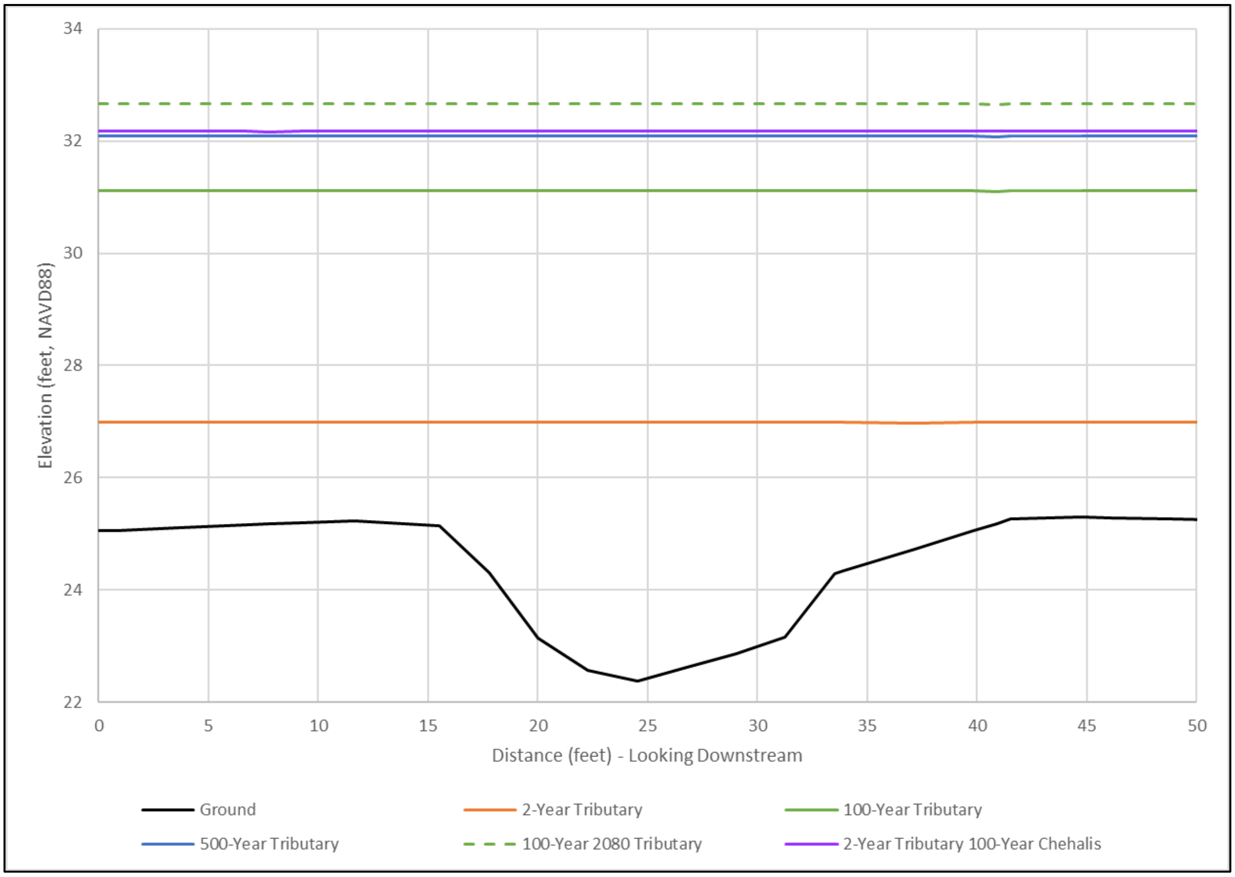

Figure 40: Typical upstream existing channel cross section at 8:00 (STA 13+82)

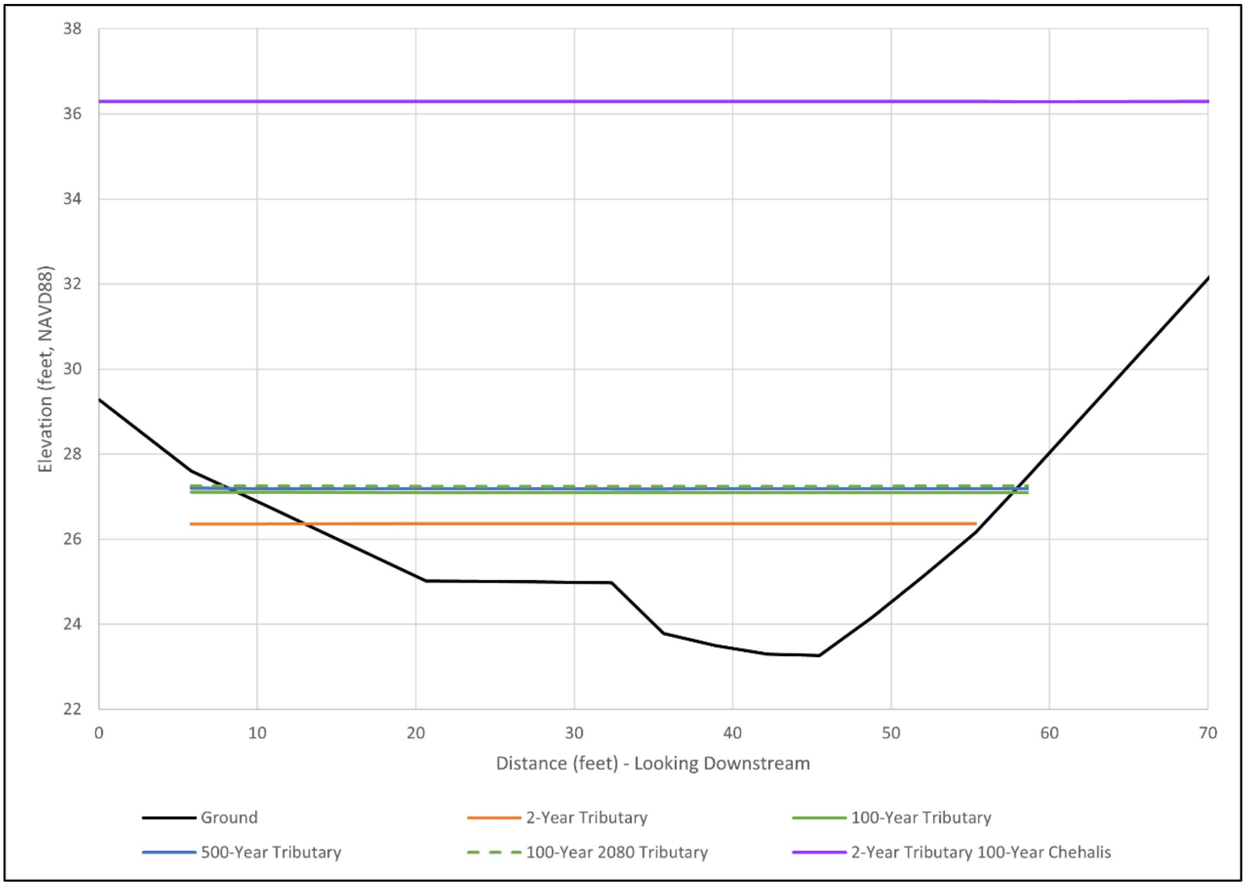

Figure 41: Typical downstream existing channel cross section at 8:00 (STA 11+27)

Figure 42 and Figure 43 show the velocities during the 100-year peak flow for the UNT to Wenzel storm event. This pattern is similar for all storm events with no Chehalis backwater. The largest velocity is seen at the outlet of the culvert and velocities are relatively slow elsewhere. This is reiterated in Table 13, where very low overbank velocities are shown.

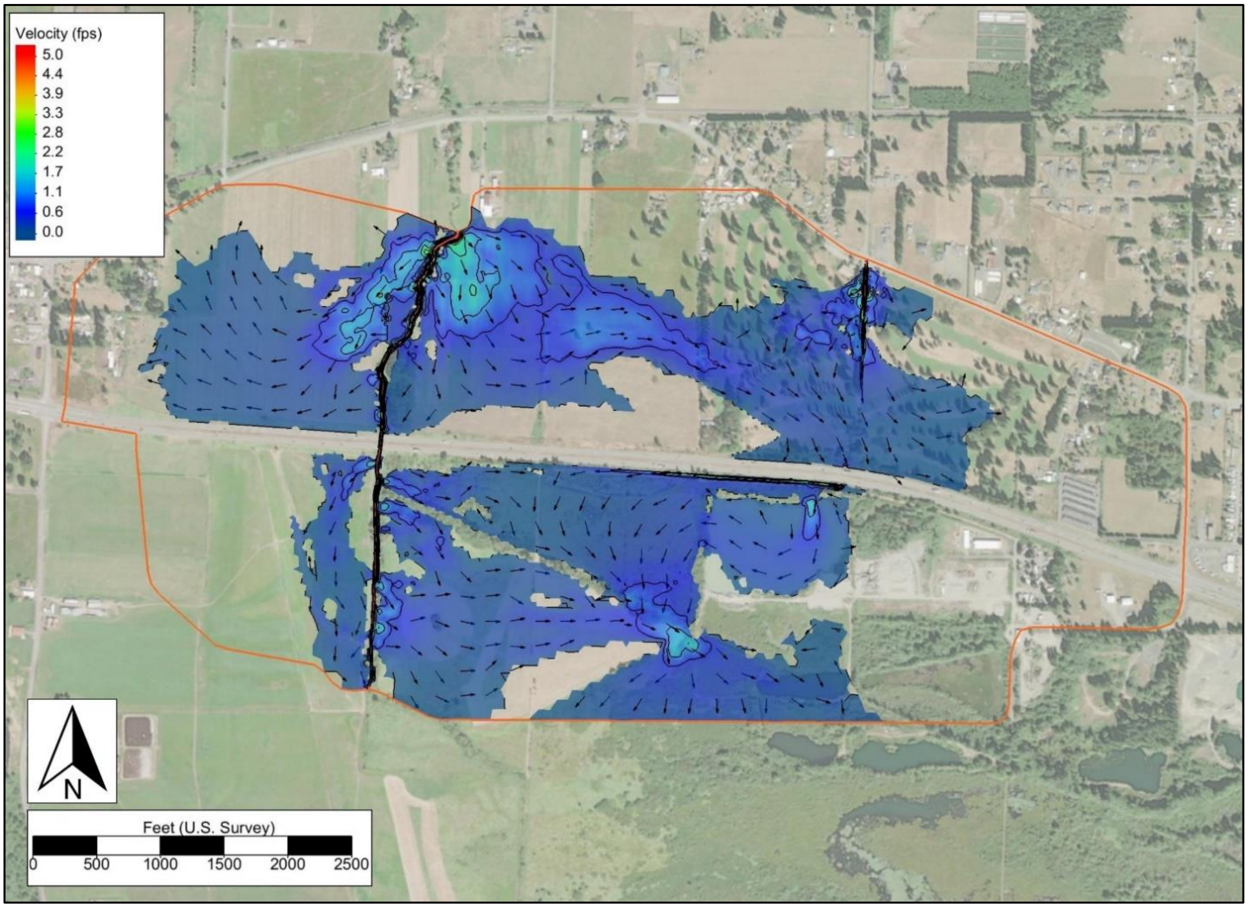

Figure 42: Existing-conditions 100-year velocity map at 8:00

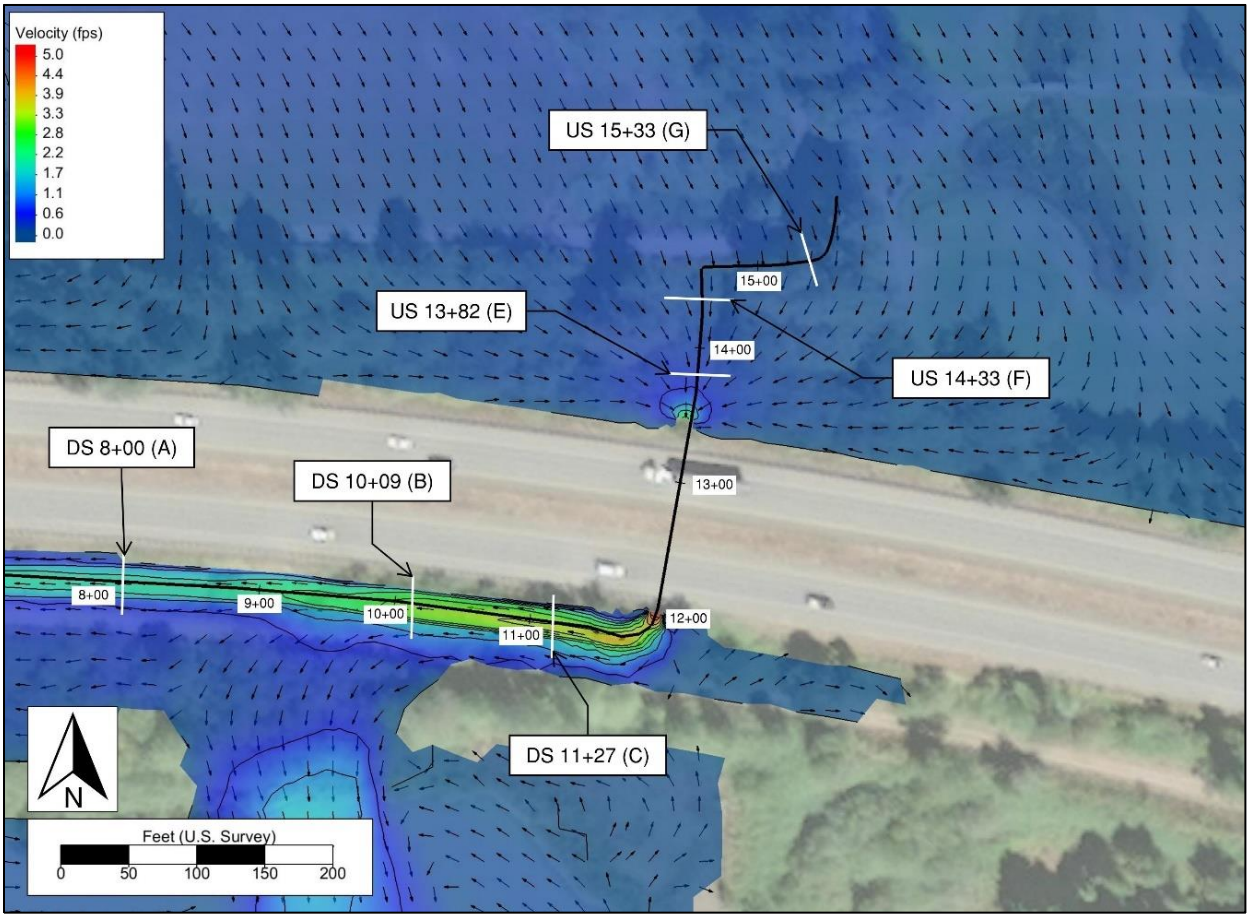

Figure 43: Channel view of existing-conditions 100-year velocity map at 8:00 with cross-section locations

Table 13: Existing-conditions average channel and floodplains velocities at 8:00

Cross-section location	100-yr UNT to Wenzel Slough, no Chehalis average velocities (ft/s)			2-yr UNT to Wenzel Slough, 100-yr Chehalis average velocities (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 8+00 (A)	0.2	1.5	0.5	0.1	0.1	0.1
DS 10+09 (B)	NA	2.7	1.2	0.1	0.1	0.1
DS 11+27 (C)	0.0	2.6	1.3	0.2	0.3	0.2
Structure (D)	NA	NA	NA	NA	NA	NA
US 13+82 (E)	0.4	0.4	0.3	0.7	1.6	0.4
US 14+33 (F)	0.2	0.2	0.1	0.5	1.2	1.1
US 15+33 (G)	0.1	0.1	0.1	0.6	0.5	0.3

Right overbank (ROB)/left overbank (LOB) locations were approximated by inspection of channel banks in the topography.

Because of the influence of the Chehalis River backwater at this crossing, the most critical WSE for design purposes occurs during the 2-year UNT to Wenzel and 100-year Chehalis River flood event. As explained in Section 5.1.4, both the upstream and downstream boundary conditions vary over time, with both the inflow discharge and Chehalis River stage peaking 8 hours into the run time. As a result, downstream of the crossing, the WSE peaks 8 hours into the simulations at a height of 36.3 feet, which is the maximum stage of the Chehalis River during a 100-year flood. Upstream of the crossing, however, the WSE reaches its peak almost 2 hours later, at 9:50. This delay occurs because the Newman Creek crossing and UNT to Wenzel crossing, which are undersized, cannot convey the Chehalis backwater quickly. Instead, for 2 hours after the Chehalis peak at 8:00, pressure head on the south side of US 12 continues to push water backwards (north) through the culvert until the Chehalis stage, and therefore the downstream head, falls below the WSE built up upstream of the US 12 crossing. After this point has been reached, the flooded area upstream of the US 12 crossing begins to drain. So, the peak WSE upstream of the crossing occurs almost 2 hours after the peak Chehalis stage ultimately reaching a WSE of 34.5 feet. This WSE is 1.8 feet lower than the peak Chehalis stage because the existing crossings are undersized for a Chehalis backwater event.

It is unlikely that this large of a difference between the upstream and downstream WSEs actually occurs, however. As explained in Section 5.1.6, the model does not account for other ways the Chehalis floodwater can reach the north side of US 12. So, the WSE upstream of the crossing is likely much closer to equalizing with the 36.3-foot WSE of the Chehalis River.

The largest shear stress event across both upstream and downstream is the 2-year UNT to Wenzel with 100-year Chehalis River event. The highest sheer stress upstream of the culvert is seen at 4:50, which is when the Chehalis flooding reaches upstream of the culvert, with a value of 0.2 lb/SF. Downstream of the culvert, the peak is reached at 14:50, when the area north of US 12 is draining, with a value of 0.3 lb/SF. This shear stress is likely caused by the sharp turn the channel takes immediately downstream of the crossing.

The largest velocities under existing conditions occur during the 2-year UNT to Wenzel and 100-year Chehalis River flood event. Similar to the shear stress, the peak velocity upstream of the crossing occurs of 1.7 ft/s while the Chehalis pushes through the culvert at 4:50, and the peak velocity downstream of the crossing of 2.4 ft/s occurs during the draining at 15:30.

A summary of the peak WSE, shear stress, and velocity is shown in Table 14.

Table 14: Summary of existing-conditions peaks of hydraulic parameters

Hydraulic parameter	Event	Upstream		Downstream	
		Peak	Time	Peak	Time
WSE (ft)	2-yr UNT, 100-yr Chehalis	34.5	9:50	36.3	8:00
Shear Stress (lb/SF)	2-yr UNT, 100-yr Chehalis	0.2	4:50	0.3	14:50
Velocity (ft/s)	2-yr UNT, 100-yr Chehalis	1.7	4:50	2.4	15:30

5.3 Natural Conditions

Natural conditions were not modelled for the PHD as part of determining the hydraulic opening.

5.4 Proposed Conditions: 26-foot Minimum Hydraulic Width

The overbank flow from Newman Creek that contributes to UNT to Wenzel Slough increased in the proposed conditions across the same cross section, as seen in Figure 44. This is because the wider hydraulic opening decreases the backwater at the UNT to Wenzel crossing of US 12 allowing more flow to move toward and through the crossing. The flow additions from Newman Creek increased from existing conditions by approximately 10%, 20%, and 40% at the peak for the 100-, 500- and 2080 projected 100-year flows respectively.

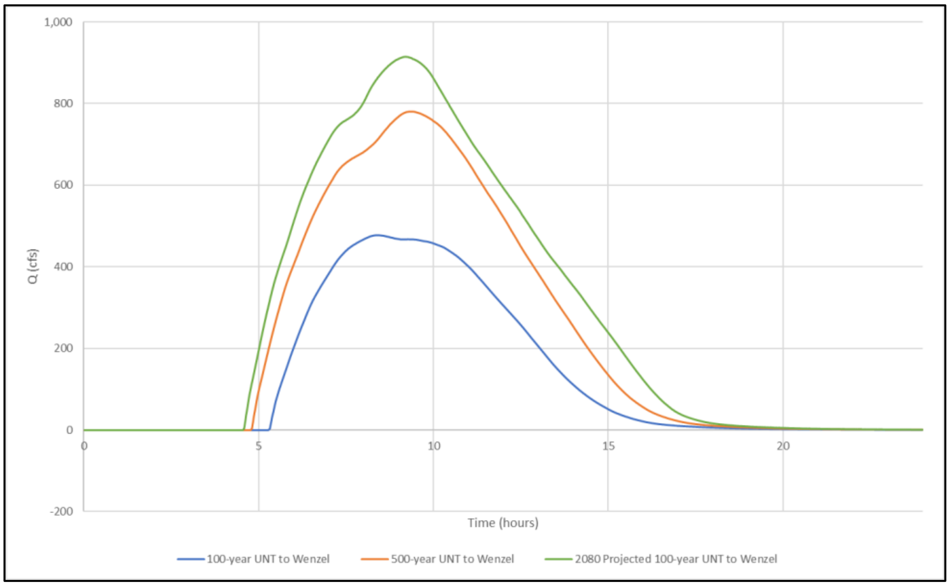

Figure 44: Proposed conditions flow between Newman Creek and UNT to Wenzel

Figure 45 shows the locations of cross sections used in Table 15. The proposed design no longer backwaters during the 2-year UNT to Wenzel event, as seen in Figure 46. The crossing, however, does still backwater during all other flood events. Figure 47 shows a cross section through the proposed structure with the 2-year UNT to Wenzel event just slightly above the channel banks, as is expected. Figure 48 and Figure 49 demonstrate that the largest velocity is still seen at the culvert outlet for flows with no Chehalis backwater. However, the flow velocities in the main channel and overbanks have increased, as seen in Table 16, due to the increased conveyance of the design.

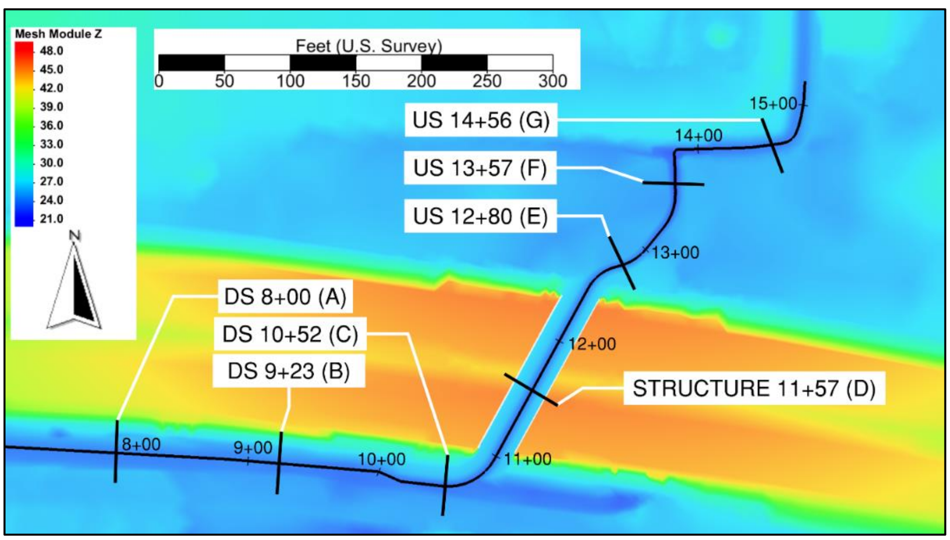

Figure 45: Locations of cross sections on proposed alignment used for results reporting

Table 15: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS 8+00 (A)	26.4	27.6	28.0	27.8
	DS 9+23 (B)	26.4	27.6	28.1	27.9
	DS 10+52 (C)	26.4	27.9	28.4	28.2
	Structure 11+57 (D)	26.5	28.7	29.6	29.3
	US 12+80 (E)	27.0	30.3	31.8	31.2
	US 13+57 (F)	27.0	30.4	31.8	31.2
	US 14+56 (G)	27.0	30.4	31.8	31.2
Max depth (ft)	DS 8+00 (A)	2.7	3.9	4.4	4.2
	DS 9+23 (B)	2.8	4.0	4.5	4.3
	DS 10+52 (C)	3.2	4.6	5.2	5.0
	Structure 11+57 (D)	3.0	5.2	6.1	5.7
	US 12+80 (E)	3.2	6.6	8.0	7.4
	US 13+57 (F)	4.4	7.8	9.2	8.7
	US 14+56 (G)	3.4	6.7	8.1	7.6
Average velocity (ft/s)	DS 8+00 (A)	1.0	2.2	2.7	2.5
	DS 9+23 (B)	0.8	2.6	3.3	3.0
	DS 10+52 (C)	1.2	3.5	4.4	4.1
	Structure 11+57 (D)	2.1	6.6	8.1	7.5
	US 12+80 (E)	1.0	1.3	1.5	1.4
	US 13+57 (F)	0.2	0.4	0.4	0.4
	US 14+56 (G)	1.1	0.3	0.3	0.3
Average shear (lb/SF)	DS 8+00 (A)	0.0	0.1	0.2	0.1
	DS 9+23 (B)	0.0	0.2	0.3	0.2
	DS 10+52 (C)	0.1	1.7	2.6	2.2
	Structure 11+57 (D)	0.1	0.8	1.2	1.0
	US 12+80 (E)	0.0	0.2	0.2	0.2
	US 13+57 (F)	0.0	0.0	0.0	0.0
	US 14+56 (G)	0.0	0.0	0.0	0.0

Main channel extents were approximated by inspection of channel banks in the topography.

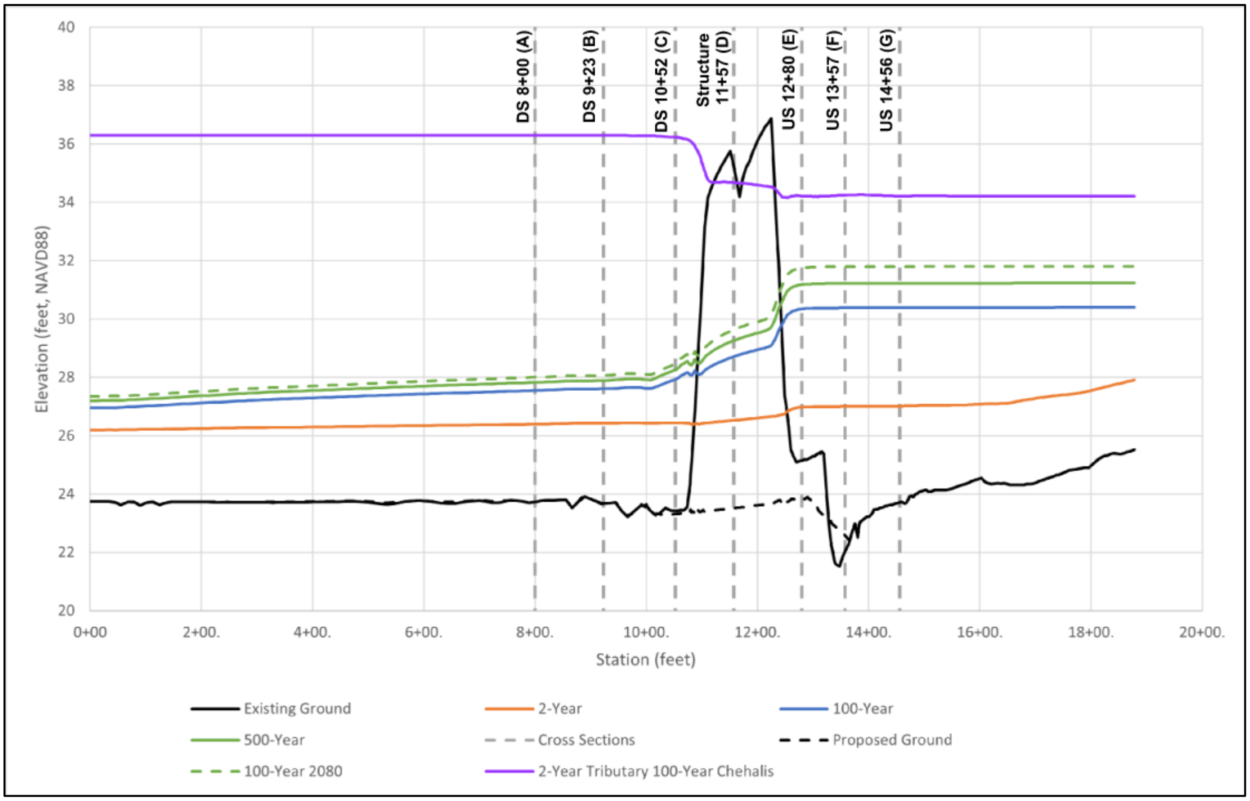

Figure 46: Proposed-conditions water surface profiles at 8:00

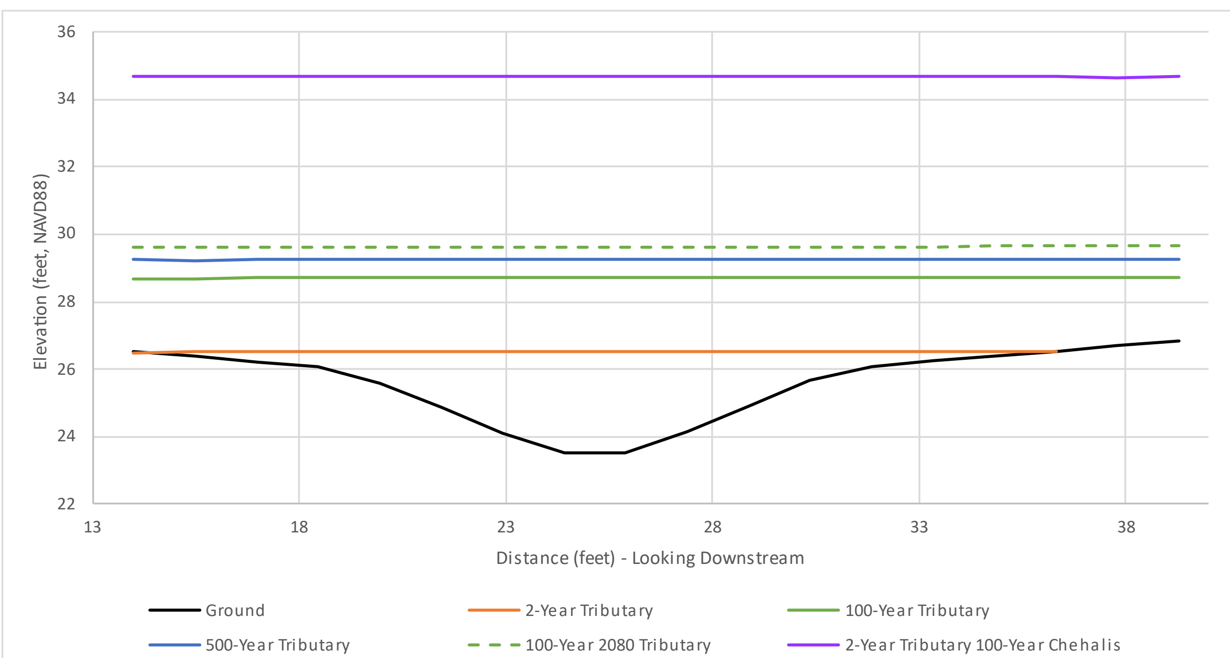

Figure 47: Typical section through proposed structure (STA 11+57) at 8:00

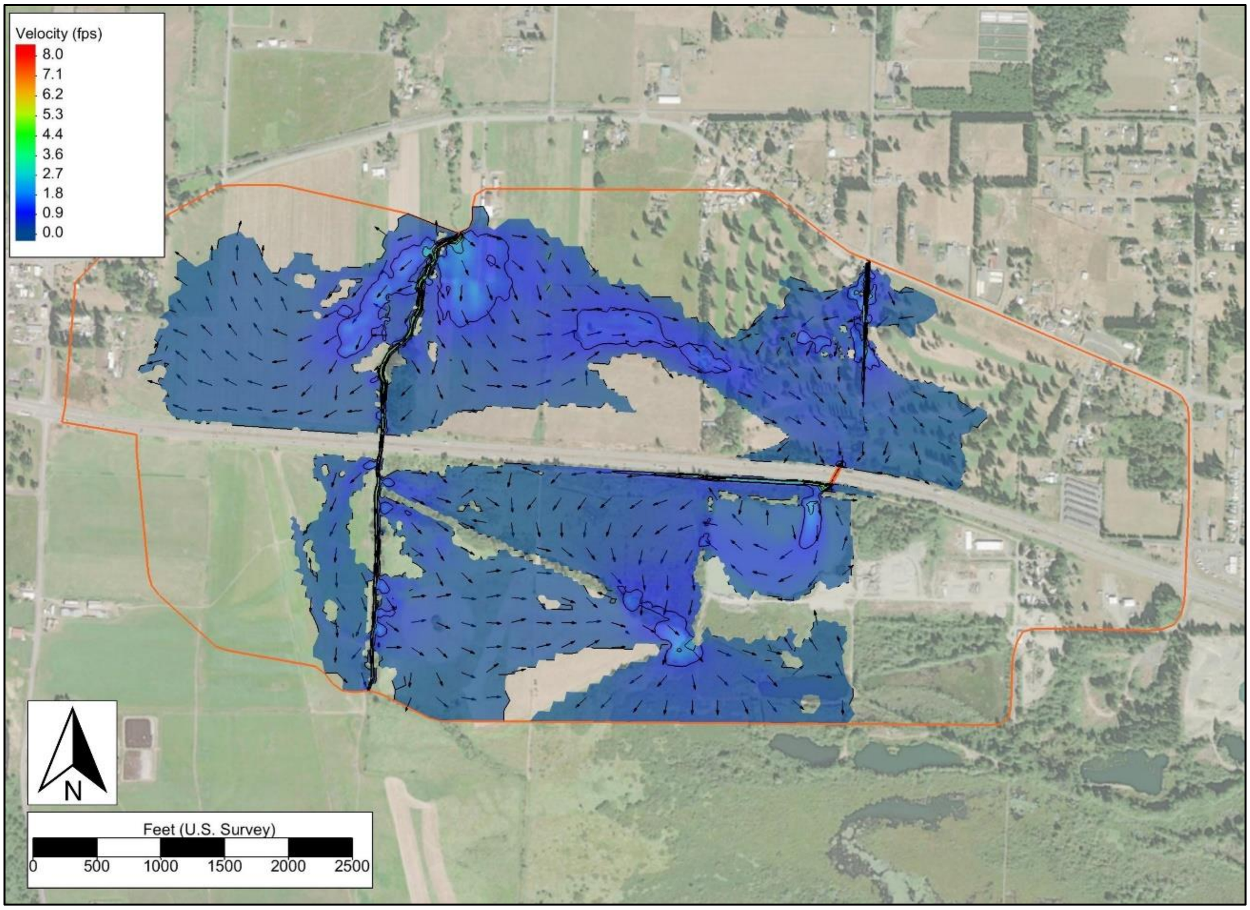

Figure 48: Proposed-conditions 100-year velocity map at 8:00

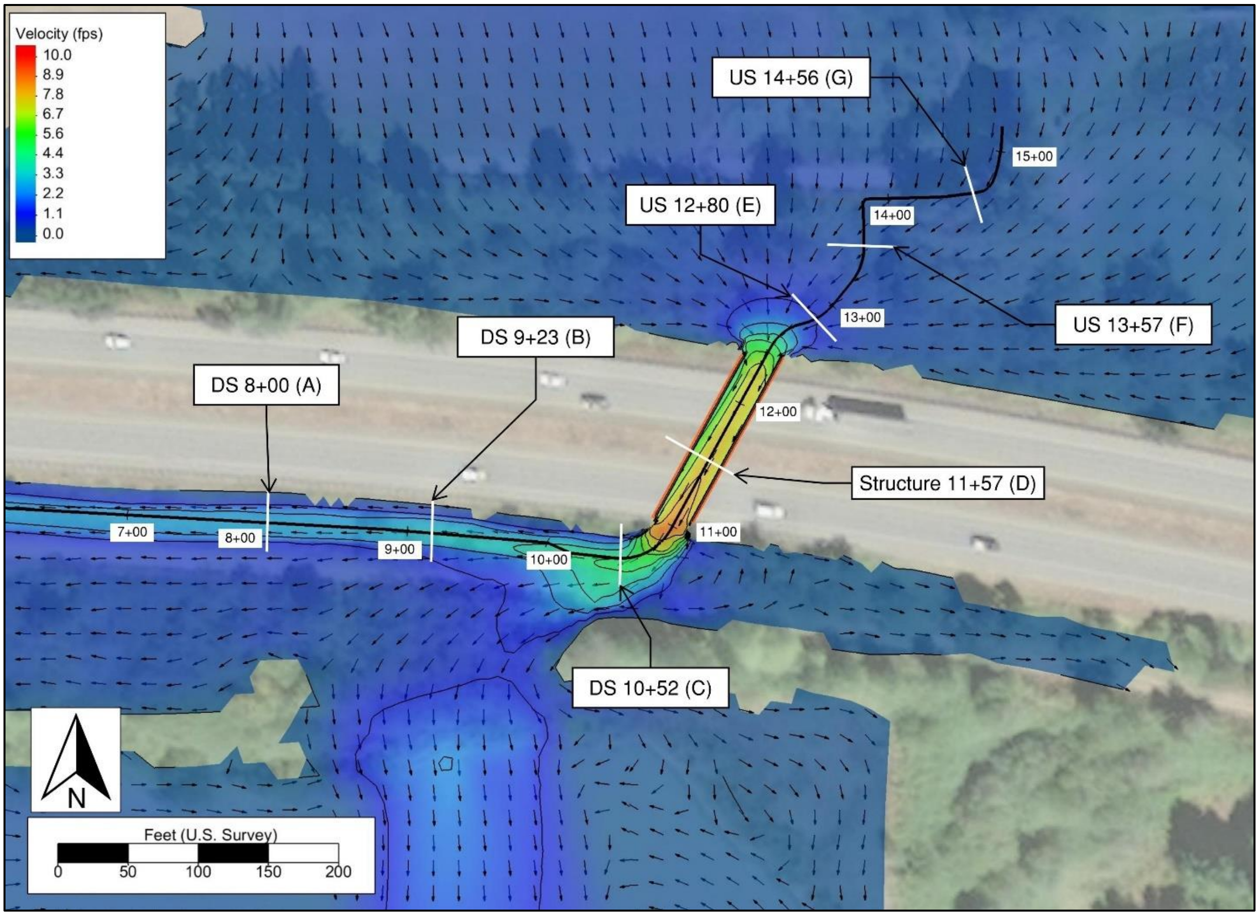

Figure 49: Channel view of proposed-conditions 100-year velocity map at 8:00 with cross-section locations

Table 16: Proposed-conditions average channel and floodplains velocities at 8:00

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 8+00 (A)	0.4	2.2	0.8	0.2	0.3	0.2
DS 9+23 (B)	0.4	2.6	1.3	0.3	0.5	0.4
DS 10+52 (C)	NA	3.5	3.9	1.6	1.8	1.4
Structure 11+57 (D)	NA	6.6	NA	NA	7.6	NA
US 12+80 (E)	1.1	1.3	1.0	5.4	4.5	1.3
US 13+57 (F)	0.4	0.4	0.4	3.2	2.9	2.6
US 14+56 (G)	0.2	0.3	0.3	1.9	1.7	1.3

Right overbank (ROB)/left overbank (LOB) locations were approximated by inspection of channel banks in the topography.

As discussed in Section 5.2, the 2-year UNT to Wenzel and 100-year Chehalis River flood event provides the WSE that will be used in design. As occurs under existing conditions, the WSE downstream of the US 12 crossing peaks at 36.3 feet at 8:00, which is when the Chehalis stage peaks. Through the crossing, a peak of 35.4 feet is reached at 9:00. Upstream of the crossing, the peak WSE occurs 1 hour and 10 minutes later than it occurs downstream, at 9:10. This delay in WSE peak upstream of the crossing is 40 minutes shorter under proposed conditions than under existing conditions. This is because the proposed wider hydraulic opening conveys more water faster than the existing conditions. The increased conveyance also results in a peak WSE of 35.4 feet upstream of the crossing, which is 0.9 feet higher than the existing conditions.

As explained in Sections 5 and 5.2, the Chehalis backwater has other ways of reaching the north side of US 12 that are not included in the hydraulic model. So, the peak WSE upstream of the crossing is likely closer to 36.3 feet (the peak Chehalis stage).

The largest shear stress values under proposed conditions occur during the 2-year UNT to Wenzel and 100-year Chehalis River event. Similar to existing conditions, shear stress reached its peak upstream while the Chehalis backwaters pushed north through the culvert and reached the peak downstream while the area north of US 12 drained. However, the peak upstream shear stress under proposed conditions occurred about 2 hours later than it did under existing conditions. Additionally, the peak downstream under proposed conditions occurred about 2 hours earlier than it did under existing conditions. This time difference, along with the higher stress values of 2.9 lb/SF upstream and 4.1 lb/SF downstream indicate that the proposed design conveys the Chehalis floodwater faster than the existing conditions.

Through the proposed structure, the shear stress peaks at 1.5 lb/SF at 12:30, the same time that it peaks upstream of the crossing. At 7:00, however, when it peaks downstream, the shear stress through the structure reaches a localized peak of 1.1 lb/SF. This suggests that the proposed structure is impacted by both the Chehalis pushing north and the floodwaters draining.

Velocity follows the same trend as shear stress. The upstream peak of 4.1 ft/s occurs at 7:00 and the peak through the structure and downstream occur simultaneously at 11:50 with values of 9.5 ft/s and 4.8 ft/s respectively. These proposed velocities, similar to shear stress, occur closer to the 8:00 peak Chehalis stage than the existing conditions, as expected due to the increased conveyance. The proposed conditions velocities are also faster than the existing conditions, again due to the increase in conveyance.

A summary of the peak WSE, shear stress, and velocity is shown in Table 17.

Table 17: Summary of proposed-conditions peaks of hydraulic parameters

Hydraulic parameter	Event	Upstream		Through structure		Downstream	
		Peak	Time	Peak	Time	Peak	Time
WSE (ft)	2-yr UNT, 100-yr Chehalis	35.4	9:10	35.4	9:00	8:00	36.3
Shear Stress (lb/SF)	2-yr UNT, 100-yr Chehalis	2.9	7:00	1.5	12:30	4.1	12:30
Velocity (ft/s)	2-yr UNT, 100-yr Chehalis	4.1	7:00	9.5	11:50	4.8	11:50

6 Floodplain Evaluation

Neither Wenzel Slough nor the UNT to Wenzel Slough are specifically mapped by FEMA. However, this project is within the FEMA special flood hazard area (SFHA) Zone A floodplain for the Chehalis River; see Appendix A for FIRM.

The existing and expected proposed project conditions were evaluated to determine whether the project would cause a change in flood risk.

A flood risk assessment is being prepared for this crossing.

6.1 Water Surface Elevations

Instead of performing the floodplain analysis using the 100-year UNT to Wenzel Slough model results, as would be typical, the 2-year UNT to Wenzel Slough 100-year Chehalis River model results were used because of the large influence of the Chehalis around the crossing.

The proposed design is not expected to change the mapped FEMA SFHA. The Zone A designation of this floodplain indicates that the floodplain boundaries were derived based on topography from USGS topographic maps. The boundaries for Zone A floodplains are not typically determined with a level of detail that includes fill prisms from roads and highways such as US 12. So, even though US 12 restricts Chehalis River flooding north of the highway, it is not part of FEMAs considered floodplain hydraulics. Therefore, any changes to US 12 will not cause change in the SFHA.

Though the proposed design will not impact FEMA mapping, the larger hydraulic opening allows water to flow more freely through the crossing. Because of this, the hydraulic model predicts that the Chehalis backwater will flow through the US 12 crossing more quickly, resulting in the peak WSE north of US 12 occurring sooner. Because the WSE equilibrium between the south and north sides of US 12 occurs earlier along the flood hydrograph, there is time for additional water to reach the north side of US 12 and the peak WSE to be higher. This is seen in Figure 50. However, it is difficult to determine if the rise will occur in reality. The hydraulic model is missing factors that would more accurately describe the Chehalis backwater, such as other US 12 crossings and the Satsop River. Without a larger and more detailed hydraulic model of the Chehalis floodplain, the design team is unable to determine if the increased conveyance of the UNT crossing will really increase WSEs.

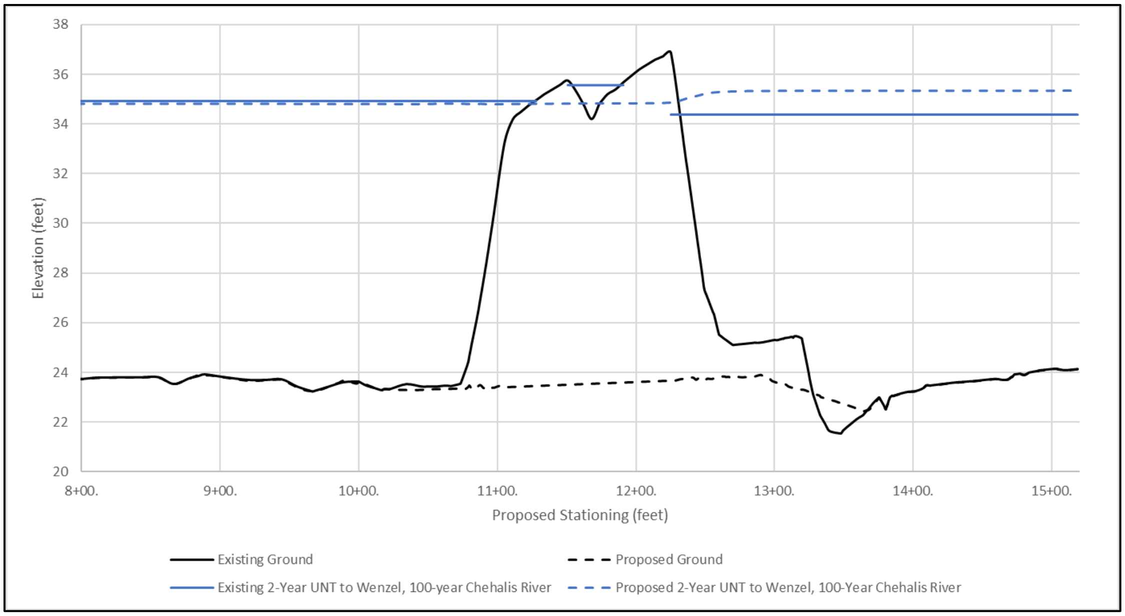

Figure 50: Existing- and proposed-conditions 2-year UNT to Wenzel Slough 100-year Chehalis River water surface profile comparison along proposed alignment

7 Final Scour Analysis

For this FHD, the risk for lateral migration, potential for long-term degradation, and evaluation of total scour are based on the final geotechnical report dated January 27, 2020.

Using the results of the hydraulic analysis (Section 5.4), based on the final structure design, and considering the potential for lateral channel migration, final scour calculations for the scour design flood and scour check flood were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson et al. 2012). Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections.

7.1 Lateral Migration

The geotechnical report indicates that the soils at the US 12 crossing are deformable, so there is a risk of lateral migration at the site. However, upstream of the US 12 crossing, the UNT passes through Oakridge Golf Course in a routinely maintained ditch, as discussed in 2.6.2. Because of this routine maintenance upstream of the crossing, expected channel migration is limited.

7.2 Long-term Degradation of the Channel Bed

Long-term changes to streambed elevations associated with man-made or natural causes are considered long-term aggradation and degradation. Aggradation is the deposition of material caused by erosion upstream of the crossing, and/or a grade control feature(s) in the stream channel downstream of the crossing. Aggradation is not a component of total scour. Conversely, degradation is the lowering or scouring of the channel bed caused by a decrease in the sediment supply from upstream, and/or removal of a grade control feature(s) in the channel downstream of the crossing. Degradation is a component of total scour.

The UNT to Wenzel Slough is expected to remain in a long-term state of dynamic equilibrium. Glacial outwash present throughout the basin, as described in the geotechnical report for this project, provides an abundant supply of sediment, which could result in aggradation under the right conditions (WSDOT 2020). However, flood water from the Chehalis River is expected to periodically pass through this crossing, which could scour out built up fine material. The dynamic equilibrium of this channel is expected to follow a pattern of small, regular flood events that cause aggradation and large, irregular flood events that scour out the deposits. This assumes that the land cover and land use characteristics in the watershed upstream of the project site will remain constant during the life of the replacement structure. If substantial changes in the watershed such as logging or urbanization occur in the future, additional sediment transport could be seen at the crossing.

7.3 Contraction Scour

Contraction scour is the lowering of the streambed elevation associated with a constriction of flow through a culvert or bridge. Estimates of contraction scour were calculated following the methodology outlined in Chapter 6 of HEC-18 (Arneson et al. 2012) for non-cohesive materials. The contraction scour condition can be classified as live-bed or clear-water scour. The scour condition is dependent on the transport of bed material upstream of the US 12 crossing. Clear-water scour occurs when there is no sediment transport, while live-bed scour occurs when there is transport of bed material from an upstream reach into the crossing. Scour condition determination is made by calculating the critical velocity of the D_{50} and comparing it to the mean velocity upstream of the crossing.

The most significant contraction scour is associated with backwater flow from the Chehalis River flood flows. Contraction scour calculations that account for Chehalis River flooding were conducted for the preliminary scour analysis (PSA) during early stages of design. The combination of approximately the 10-year flood event in the Chehalis River (as simulated by the most recent Chehalis River basin hydraulic model available at the time of the PSA) and a 2-year flow in the UNT to Wenzel Slough was found to represent the “worst-case” flow condition for scour analysis.

The resulting live-bed scour condition estimated 21 feet of scour at the US 12 crossing. There are several reasons to believe that this is an overestimate, most importantly that the proposed crossing is only 26 feet wide. Geotechnical data for the project indicates that the material at this depth consists of silty sand with gravel. If over 20 feet of scour occurred at this site, there would have to be complete removal of soil material to this depth through the crossing, which would severely damage the highway. Nowhere near that kind of damage has occurred along this section of the highway in past river flood events, though far less flow passes through the existing culvert. Numerical modeling suggests that the duration of maximum flow velocity during a receding 10-year river flood event would be extremely short (on the order of minutes). Due to these numerous uncertainties, the PSA rounded down this scour estimate to a single significant digit (20 feet).

After the completion of the PSA, the design team and comanagers discussed on November 17th, 2021 in the Design Review Meeting for the Grays Harbor County Fish Barriers – Remove Fish Barriers project, that the initial estimates of scour are likely an overestimation due to predicted scour estimates based on HEC-18 assuming instantaneous scour. In reality, scour occurs over a longer period of a flood event. The proposed design also has built-in scour resistance to sustain its low flow channel shape during short term periods of flood flows through the opening. It was also discussed in the November 17th meeting that the Natural Systems Design (NSD) independent review of the hydraulic model noted the model may have included conservative assumptions that increase the predicted velocities corresponding scour at the crossing. During the November 29th, 2021 Grays Harbor Project – Vance & Wenzel Structure Types meeting, it was determined that 15 feet of scour was a better, yet still conservative, estimate for scour depth occurring during Chehalis 500-year event. This 15-foot depth is, therefore, used for design of this crossing.

The adopted scour estimate of 15 feet accommodates the expected 2.1 feet of local scour that may occur near the inlet and outlet of the structure. It also provides an allowance for the design to remain stable if the channel experiences a combination of hydraulic forces that favor streambed particle mobilization. The hydraulic modeling completed to analyze the crossing was limited to a focused project area, and made assumptions about the boundary conditions on the edges of the model domain. These boundary assumptions confined water to a smaller area than may likely occur in the complex floodplain of the Chehalis River, overestimating the depth and duration of flood waters entering the crossing during a flood, and exiting the crossing during following a backwater event. These overestimated flood elevations in the hydraulic model, lead to deeper estimates of scour when calculated using standard engineering practices. It is expected that water surface elevations would find other openings in the US 12 road prism and would potentially overtop lower elevation portions of the road during large flood events. This real-world potential would reduce actual hydraulic forces focused on the crossing. Using the model that calculates conservative results provide a design the errs toward a flood resilient crossing that can withstand larger flood events, improving safety for the traveling public. Additionally, more investigation into the geotechnical subsurface conditions indicate the likelihood that the finer streambed materials that would easily scour are sitting atop a much more resistant glacial outwash layer at depths below approximately 7 to 10 feet below ground surface.

Considering the estimated local scour, the conservative hydraulic modeling, the likelihood of the crossing seeing hydraulic pressure relief from other adjacent culvert crossings outside the study area of the crossing, and the apparent depth of the glacial outwash layer, adopting a design scour depth of 15 feet remains conservative, and more refined than relying on a single estimate from the HEC-18 method that was not informed by the context of the project site. Applying professional engineering judgement, the depth of estimated scour for this crossing is set at 15 feet. This depth accommodates the potential for hydraulic forces to scour the top layer of native and placed streambed materials, as well as allowing for some reduced potential scouring of the more scour resistant glacial outwash sublayer 7 to 10 feet below the surface. 15 feet acknowledges varying scour potential and fits the calculated estimates to the context of the site conditions.

7.4 Local Scour

7.4.1 Abutment Scour

Abutment scour was not quantified at the crossing because it is included in the decision to address a potential 15 feet of contraction scour.

7.4.2 Bend Scour

Bend scour was calculated at the culvert inlet following the methodology outlined in HEC-23 (Lagasse et al. 2012). The culvert outlet was not evaluated for bend scour because the bend ends in a confluence with the existing channel, which would cause inaccuracies in the calculations. Depth of bend scour was estimated using Maynord's method. The analysis indicates that the depth of bend scour is 2.3 feet during the 2-year UNT to Wenzel event and 4.3 feet during the 100-year UNT to Wenzel event. This scour would occur on reaches that are not under the bridge and would be overwhelmed by an even that generated the potential 15 feet of scour. In this instance, the contraction scour is not additive with the bend scour. See Appendix K for detailed calculations.

7.5 Total Scour

Calculated total depths of scour for the scour design flood and scour check flood at the proposed UNT to Wenzel Slough bridge, as will be shown in the final plans upon their completion, are provided in Table 18. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 18. The secant pile design of this bridge accounts for the predicted scour depth.

Table 18: Scour analysis summary

Calculated Scour Components and Total Scour for US 12 UNT to Wenzel Slough		
	Scour design flood	**Scour design flood**
Long-term degradation (ft)	0	0
Contraction scour (ft)	15	15
Bend scour (ft)	4.3	0
Total depth of scour (ft)[a]	15	15

a. Bend scour is not added to the contraction scour, because in an event that could cause 15 feet of scour the influence of the channel bed becomes negligible.

8 Scour Countermeasures

To assist in the protection of the proposed UNT to Wenzel Slough structure, walls and roadway embankment, as will be shown in the final plans upon their completion, scour countermeasures were designed and evaluated utilizing guidance outlined in Bridge Scour and Stream Instability Countermeasures Hydraulic Engineering Circular No. 23 3rd Edition (HEC-23) (Lagasse et al., 2009). Calculations (Appendix M) for each method were based on channel hydraulics modeled utilizing SRH-2D as described in Section 5.

The piles of the bridge and wingwalls will extend below the anticipated scour depth. The wingwalls also extend beyond the maximum top width of the potential scour hole. Additionally, buried below 2 feet of native streambed sediment in the proposed channel, a coarse mix is proposed, as discussed in Section 4.3.1. This sediment will be layered in 1-foot lifts with slash material to consolidate the matrix to resist scour. The details of the meander bars and coarse sediment layers can be found in Appendix D.

9 Summary

Table 19 presents a summary of the results of this PHD Report.

Table 19: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	8,796 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	10 ft	2.7.2 Channel Geometry
	Concurrence BFW	10 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	N/A	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	Greater than 3.0	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	435 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	646 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	No	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	Yes	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	0.3%	2.6.2 Existing Conditions
	Reference reach	0.2%	2.7.1 Reference Reach Selection
	Proposed	0.22%	4.1.3 Channel Gradient
Hydraulic width	Existing	9 ft (2 4.5-foot diameter CMPs)	2.6.2 Existing Conditions
	Proposed	26 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	3 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	100 yr Chehalis	4.2.3 Vertical Clearance
	Maintenance clearance	Recommended 6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	144 ft	2.6.2 Existing Conditions
	Proposed	138 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	Yes	4.2.6 Structure Type
	Type	Buried Bridge	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	Meander bars	3	4.3.2 Channel Complexity
	Boulder clusters	None	4.3.2 Channel Complexity
	Coarse bands	None	4.3.2 Channel Complexity
	Mobile wood	No	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	Yes	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	No	6 Floodplain Evaluation
Scour	Analysis	See link	7
	Scour countermeasures	Yes	8 Scour Countermeasures
Channel degradation	Potential?	No	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	No	7.2 Long-term Degradation of the Channel Bed

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form (Not Used)

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning's Calculations (Not Used)

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

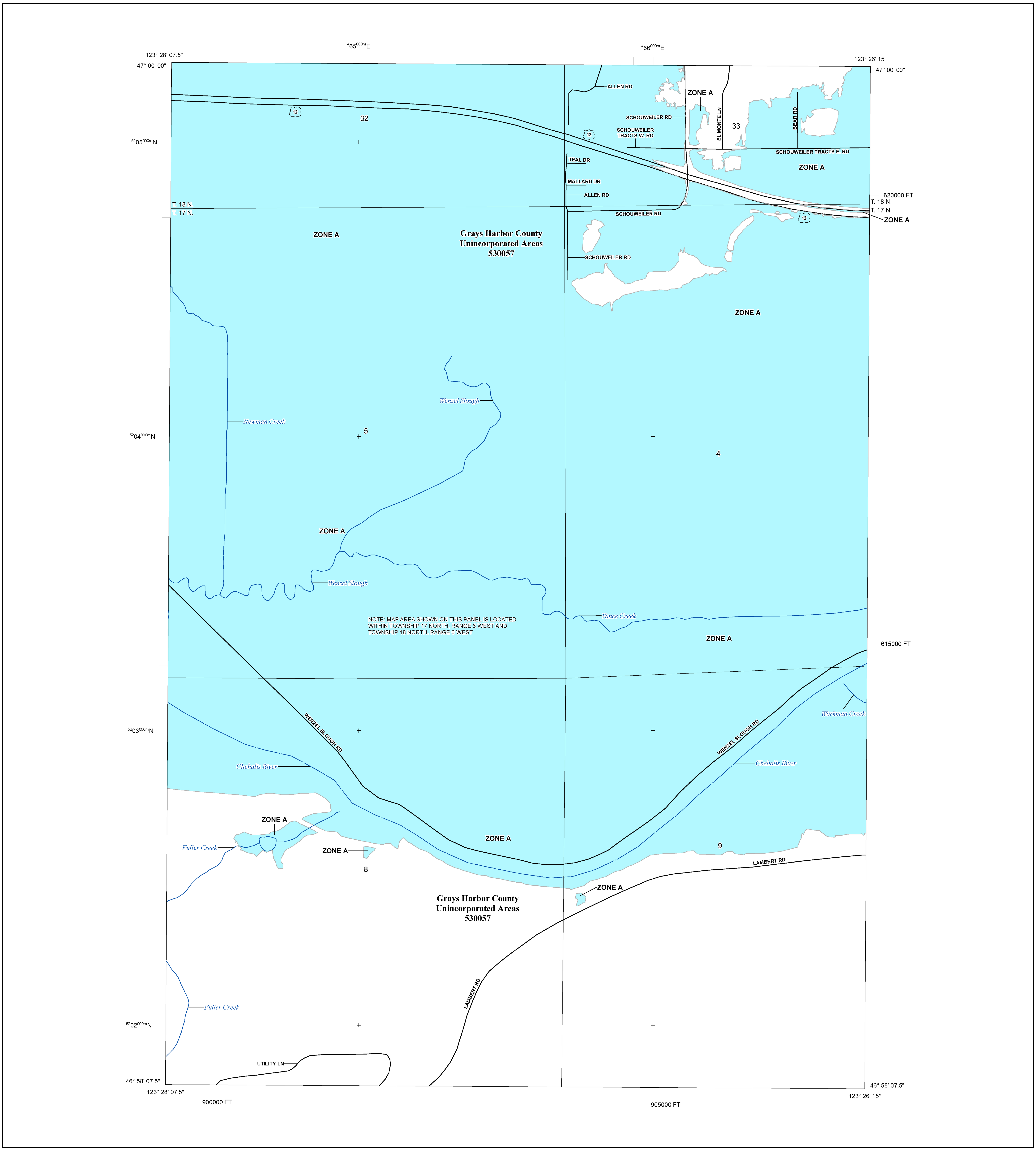
Appendix J: Reach Assessment (Not Used)

Appendix K: Scour Calculations

Appendix L: Floodplain Analysis

Appendix M: Scour Countermeasure Calculations (Not Used)

Appendix A: FEMA Floodplain Map



FLOOD HAZARD INFORMATION

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

THE INFORMATION DEPICTED ON THIS MAP AND SUPPORTING DOCUMENTATION ARE ALSO AVAILABLE IN DIGITAL FORMAT AT

HTTPS://MSC.FEMA.GOV

SPECIAL FLOOD HAZARD AREAS	Without Base Flood Elevation (BFE) *Zone A,V, A99*
	With BFE or Depth *Zone AE, AO, AH, VE, AR*
	Regulatory Floodway
OTHER AREAS OF FLOOD HAZARD	0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
	Future Conditions 1% Annual Chance Flood Hazard *Zone X*
	Area with Reduced Flood Risk due to Levee See Notes. *Zone X*
	Area with Flood Risk due to Levee *Zone D*
OTHER AREAS	NO SCREEN Area of Minimal Flood Hazard *Zone X*
	Area of Undetermined Flood Hazard *Zone D*
GENERAL STRUCTURES	Channel, Culvert, or Storm Sewer
	Levee, Dike, or Floodwall
	E 18.2 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation
	8 Coastal Transect
	Coastal Transect Baseline
	Profile Baseline
	Hydrographic Feature
	513 Base Flood Elevation Line (BFE)
OTHER FEATURES	Limit of Study
	Jurisdiction Boundary

NOTES TO USERS

For information and questions about this Flood Insurance Rate Map (FIRM), available products associated with this FIRM, including historic versions, the current map date for each FIRM panel, how to order products, or the National Flood Insurance Program (NFIP) in general, please call the FEMA Map Information eXchange at 1-877-FEMA-MAP (1-877-336-2627) or visit the FEMA Flood Map Service Center website at https://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the website.

Communities annexing land on adjacent FIRM panels must obtain a current copy of the adjacent panel as well as the current FIRM Index. These may be ordered directly from the Flood Map Service Center at the number listed above.

For community and countywide map dates refer to the Flood Insurance Study Report for this jurisdiction.

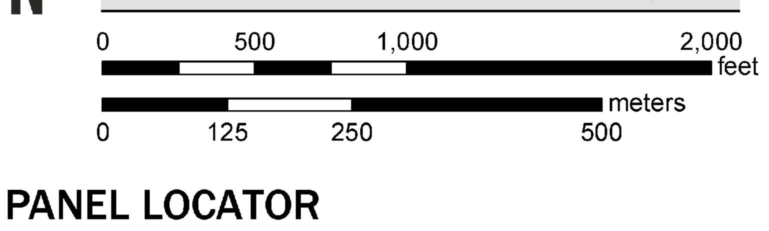
To determine if flood insurance is available in the community, contact your Insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

Base map information shown on this FIRM was provided in digital format by the Washington Department of Transportation dated 6/15/2017, the U.S. Census Bureau TIGER files dated 6/1/2016 and the Federal Emergency Management Agency effective Flood Insurance Study spatial files dated 2/3/2017.

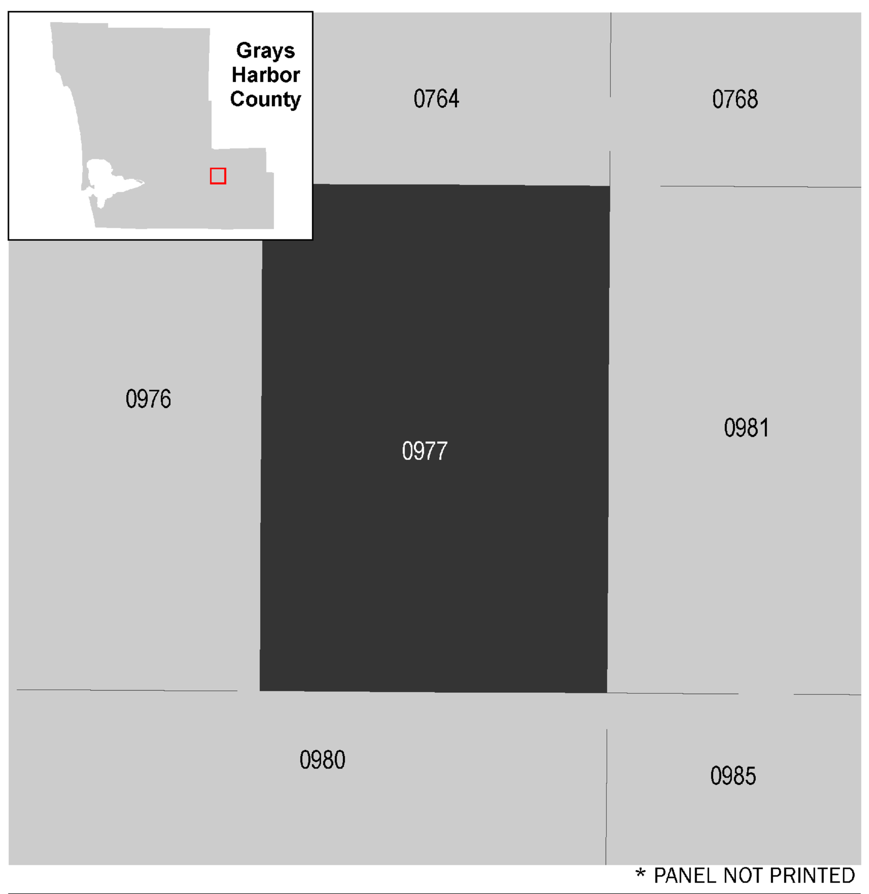
SCALE

Map Projection:
NAD 1983 UTM Zone 10N;
Western Hemisphere; Vertical Datum: NAVD 88

1 inch = 500 feet **1:6,000**



PANEL LOCATOR



* PANEL NOT PRINTED

FEMA
National Flood Insurance Program

NATIONAL FLOOD INSURANCE PROGRAM
FLOOD INSURANCE RATE MAP

GRAYS HARBOR COUNTY, WASHINGTON
And Incorporated Areas

PANEL **977** OF **1295**

Panel Contains:

COMMUNITY	NUMBER	PANEL	SUFFIX
GRAYS HARBOR COUNTY	530057	0977	E

VERSION NUMBER
2.3.3.5

MAP NUMBER
53027C0977E

MAP REVISED
SEPTEMBER 18, 2020

Appendix B: Hydraulic Field Report Form (Not Used)

A hydraulic field report form was never completed for this site because it was not required when the PHD was written.

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	**Grays Harbor - Trib. To Wenzel Slough**
By:	**Roxanne Wilcox, EIT**

Design Gradation:				
Location:	Proposed Channel			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	0.33	0.23	0.12	0.03
in	4.00	2.78	1.41	0.32
mm	102	71	35.7	8.1

Design Gradation:				
Location:				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0	0

Design Gradation:				
Location:				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0	0

Design Gradation:				
Location:				
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft				
in				
mm				

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		Streambed	Streambed Cobbles					Streambed Boulders			D_{size}
[in]	[mm]	Sediment	4"	6"	8"	10"	12"	12"-18"	18"-28"	28"-36"	
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				100.0
5.0	127			80	68	57	45				100.0
4.0	102		100	71	57	45	39				100.0
3.0	76.2		80	63	45	38	34				88.0
2.5	63.5	100	65	54	37	32	28				79.0
2.0	50.8	92.5	50	45	29	25	22				67.0
1.5	38.1	79	35	32	21	18	16				52.7
1.0	25.4	66	20	18	13	12	11				38.4
0.50	12.7	48	5	5	5	5	5				22.2
0.19	4.75	29									11.6
0.02	0.425	10									4.0
0.003	0.0750	5									2.0
% per category		40	60	0	0	0	0	0	0	0	*--> 100%*
% Cobble & Sediment		40.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*100.0%*

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

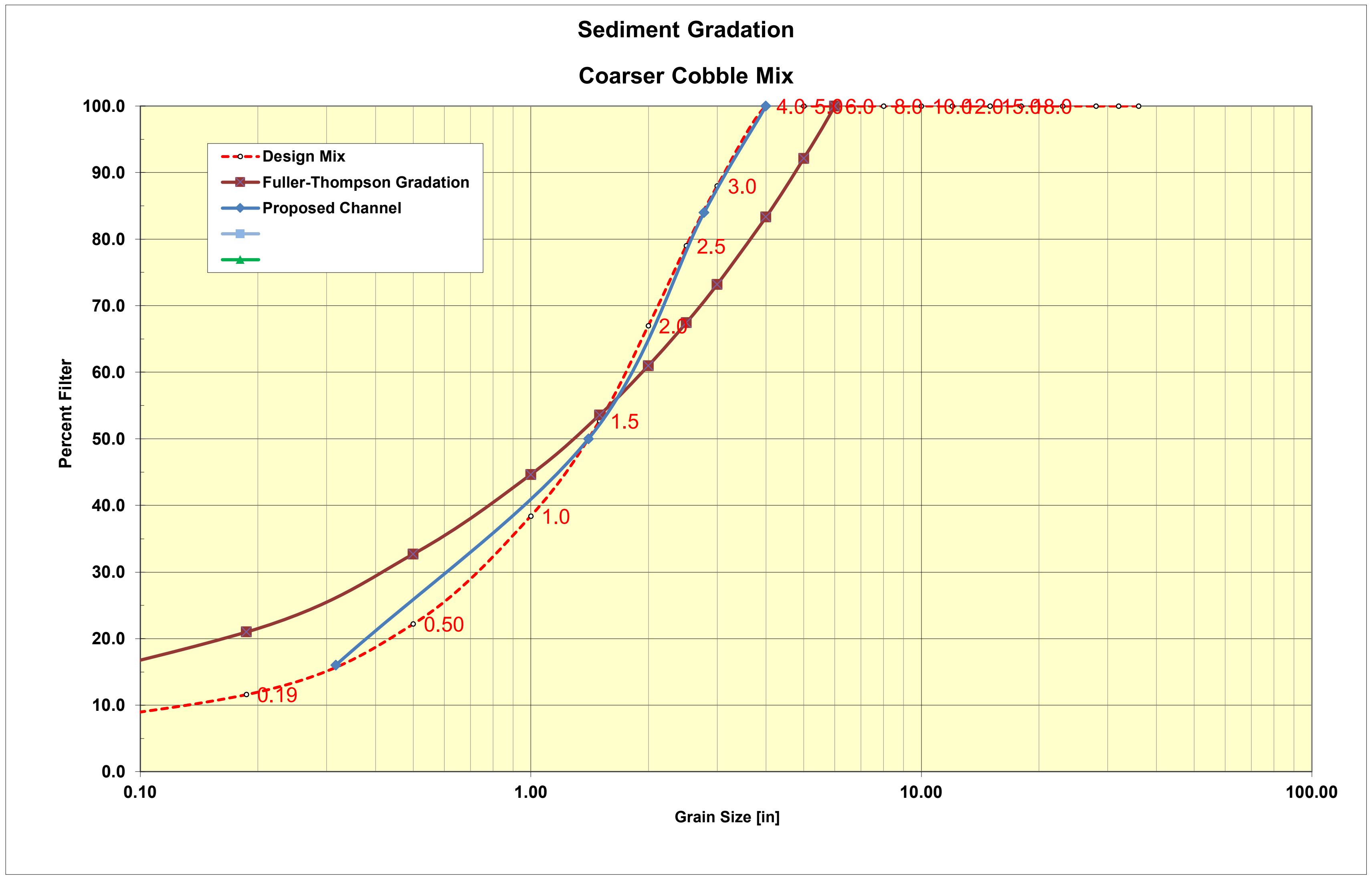
Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	100-Year	500-Year	2080 100-Year	2-Year Wenzel 100-Year Chehalis	
Average Modeled Shear Stress (lb/ft^2)	0.15	1.02	1.24	1.37	1.48	
τ_{ci}						
1.59	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.53	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.47	No Motion	No Motion	No Motion	No Motion	Motion	No Motion
1.39	No Motion	No Motion	No Motion	No Motion	Motion	No Motion
1.29	No Motion	No Motion	No Motion	Motion	Motion	No Motion
1.22	No Motion	No Motion	Motion	Motion	Motion	No Motion
1.14	No Motion	No Motion	Motion	Motion	Motion	No Motion
1.08	No Motion	No Motion	Motion	Motion	Motion	No Motion
1.01	No Motion	Motion	Motion	Motion	Motion	No Motion
0.93	No Motion	Motion	Motion	Motion	Motion	No Motion
0.88	No Motion	Motion	Motion	Motion	Motion	No Motion
0.82	No Motion	Motion	Motion	Motion	Motion	No Motion
0.75	No Motion	Motion	Motion	Motion	Motion	No Motion
0.71	No Motion	Motion	Motion	Motion	Motion	No Motion
0.67	No Motion	Motion	Motion	Motion	Motion	No Motion
0.61	No Motion	Motion	Motion	Motion	Motion	No Motion
0.54	No Motion	Motion	Motion	Motion	Motion	No Motion
0.44	No Motion	Motion	Motion	Motion	Motion	No Motion

D50	1.41	in
	0.12	ft
	35.7	mm

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010



Fuller-Thompson Gradation

Dmax =	**6**
D[in]	
12.000	136.60
10.000	125.84
8.000	113.82
6.000	100.00
5.000	92.12
4.000	83.32
3.000	73.20
2.500	67.44
2.000	61.00
1.500	53.59
1.000	44.65
0.500	32.69
0.187	21.00
0.017	7.09
0.003	3.25

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Summary - Stream Simulation Bed Material Design

Project:	**Grays Harbor - Trib. To Wenzel Slough**
By:	**Roxanne Wilcox, EIT**

Design Gradation:

Location: Proposed Channel

	D_{100}	D_{84}	D_{50}	D_{16}
ft	1.50	1.39	1.17	0.09
in	18.00	16.72	14.00	1.06
mm	457	425	355.6	26.9

Design Gradation:

Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0	0

Design Gradation:

Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0	0

Design Gradation:

Location:

	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in				
mm				

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		Streambed	Streambed Cobbles					Streambed Boulders			D_{size}
[in]	[mm]	Sediment	4"	6"	8"	10"	12"	12"-18"	18"-28"	28"-36"	
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			62.5
12.0	305						100				25.0
10.0	254					100	80				25.0
8.0	203				100	80	68				25.0
6.0	152			100	80	68	57				25.0
5.0	127			80	68	57	45				25.0
4.0	102		100	71	57	45	39				25.0
3.0	76.2		80	63	45	38	34				25.0
2.5	63.5	100	65	54	37	32	28				25.0
2.0	50.8	92.5	50	45	29	25	22				23.1
1.5	38.1	79	35	32	21	18	16				19.8
1.0	25.4	66	20	18	13	12	11				16.5
0.50	12.7	48	5	5	5	5	5				12.0
0.19	4.75	29									7.3
0.02	0.425	10									2.5
0.003	0.0750	5									1.3
% per category		25	0	0	0	0	0	75	0	0	--> 100%
% Cobble & Sediment		100.0	0.0	0.0	0.0	0.0	0.0	300.0	0.0	0.0	25.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

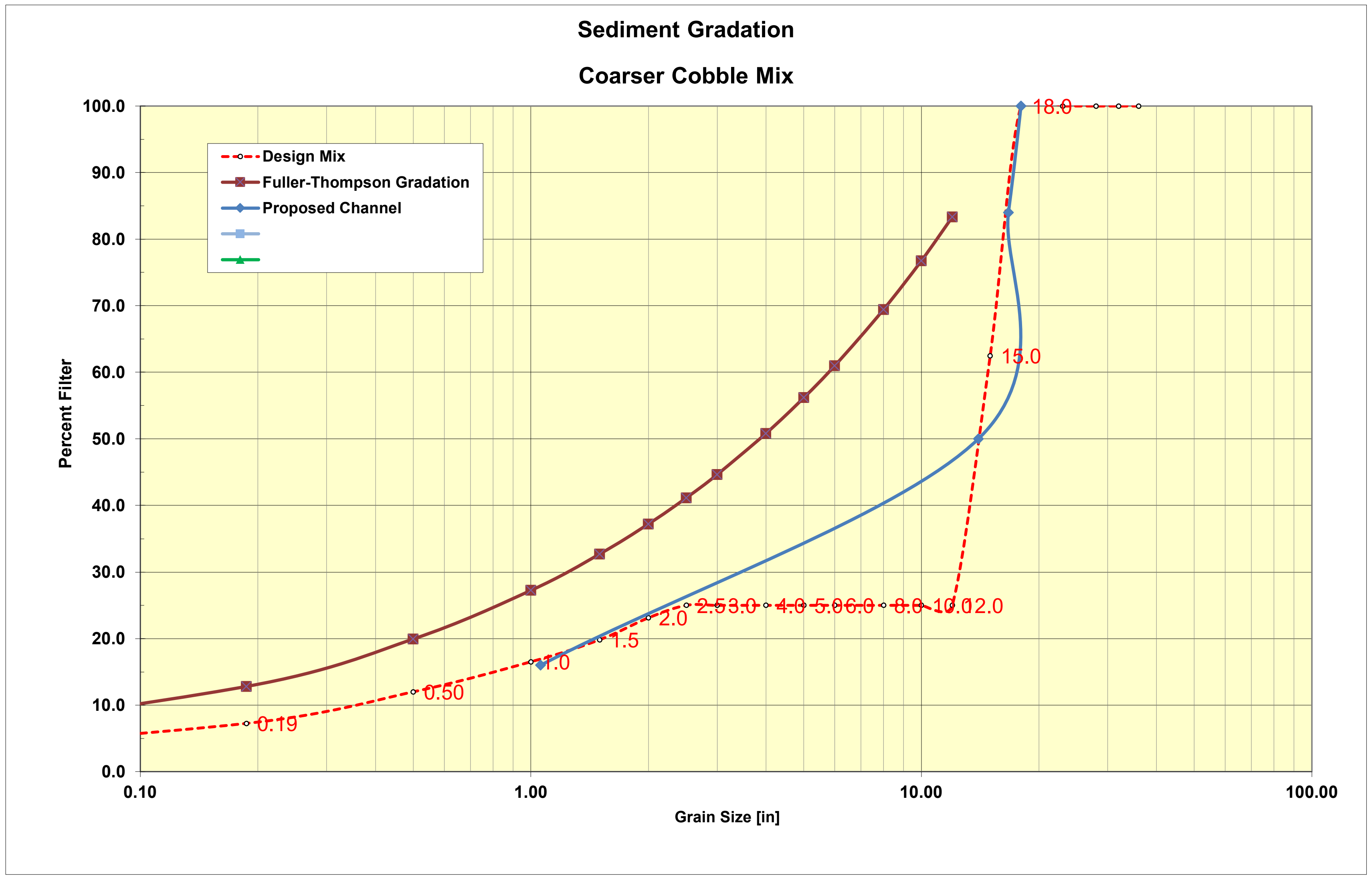
Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.054	dimensionless Shields parameter for D50, use table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Flow	2-Year	100-Year	500-Year	2080 100-Year	2-Year Wenzel	100-Year Chehalis
Average Modeled Shear Stress (lb/ft^2)	0.15	1.02	1.24	1.37	1.48	
τ_{ci}						
8.58	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
8.28	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
7.96	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
7.50	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
6.97	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
6.60	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
6.17	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
5.84	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
5.46	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
5.01	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
4.75	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
4.44	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
4.07	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.86	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.61	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.31	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.93	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.38	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion

D50	14.00	in
	1.17	ft
	355.6	mm

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

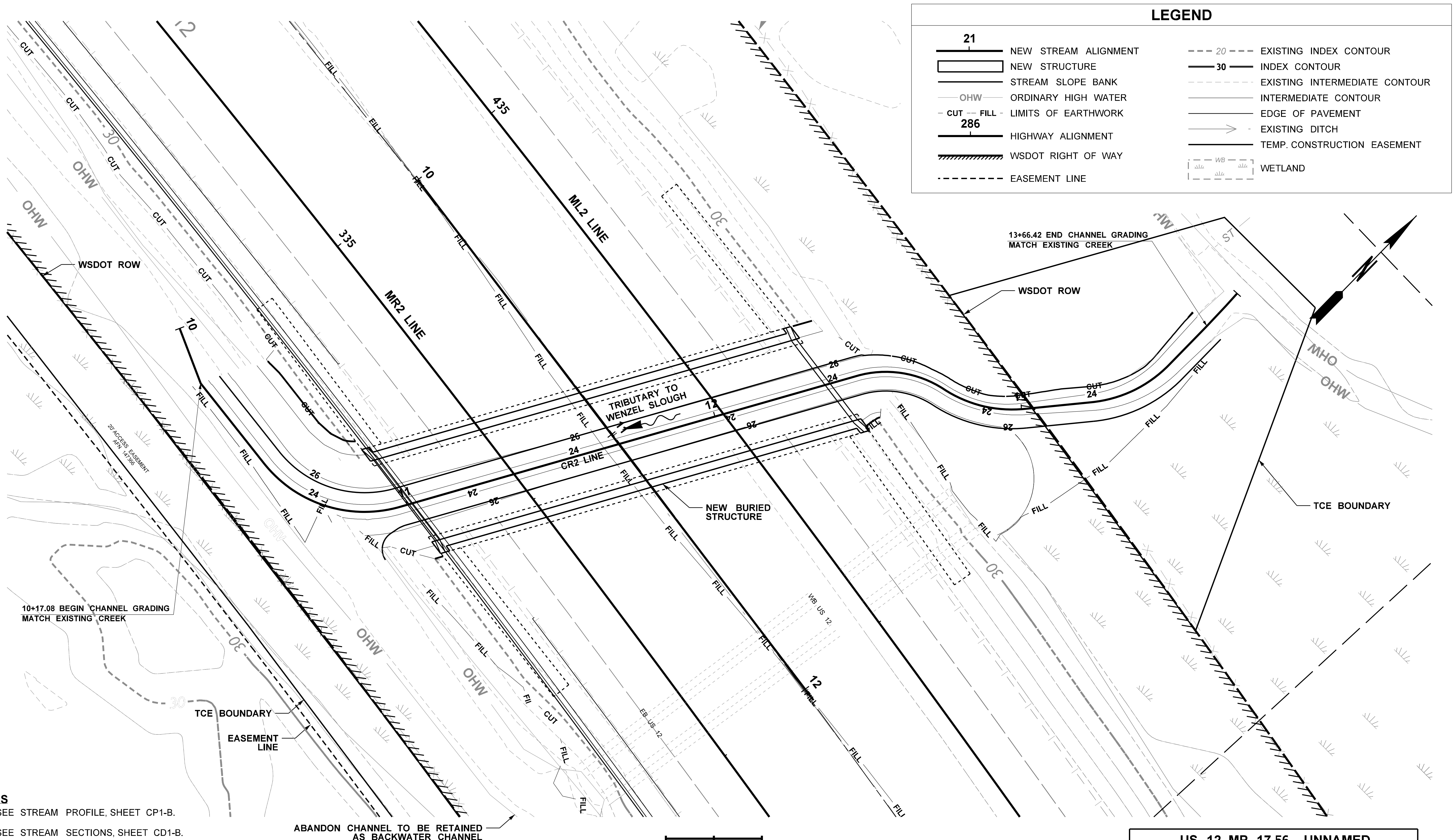


Fuller-Thompson Gradation

Dmax =	**18**
D[in]	
12.000	83.32
10.000	76.76
8.000	69.43
6.000	61.00
5.000	56.19
4.000	50.82
3.000	44.65
2.500	41.13
2.000	37.20
1.500	32.69
1.000	27.23
0.500	19.94
0.187	12.81
0.017	4.32
0.003	1.98

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Appendix D: Stream Plan Sheets, Profile, Details



NOTES

1. SEE STREAM PROFILE, SHEET CP1-B.
2. SEE STREAM SECTIONS, SHEET CD1-B.
3. SEE LWM, SHEET LWM1-B.

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

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DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PLAN

PLAN REF NO CR1-B

SHEET OF SHEETS

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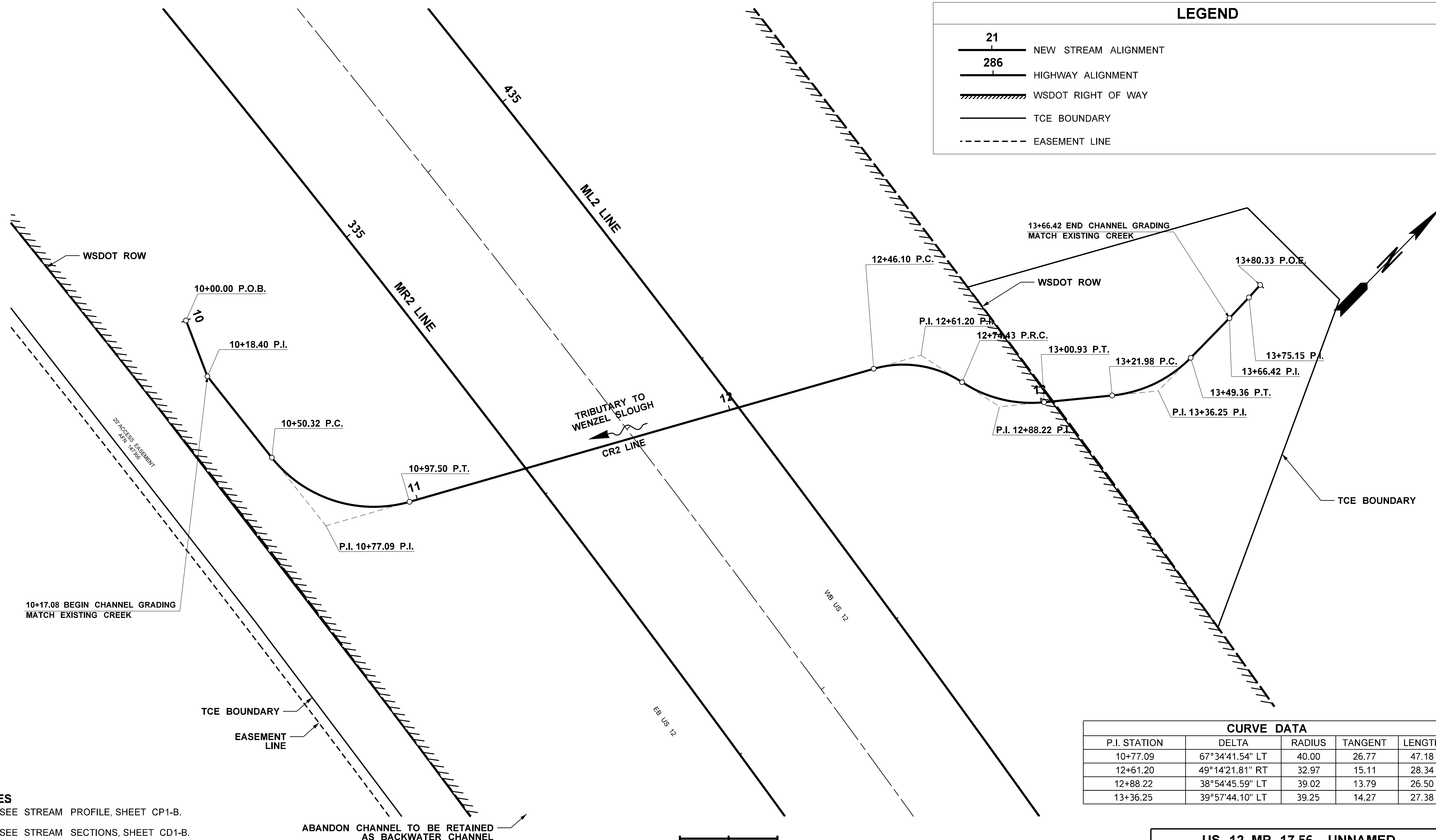

LEGEND

21	NEW STREAM ALIGNMENT
286	HIGHWAY ALIGNMENT
	WSDOT RIGHT OF WAY
	TCE BOUNDARY
	EASEMENT LINE

CURVE DATA

P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH
10+77.09	67°34'41.54" LT	40.00	26.77	47.18
12+61.20	49°14'21.81" RT	32.97	15.11	28.34
12+88.22	38°54'45.59" LT	39.02	13.79	26.50
13+36.25	39°57'44.10" LT	39.25	14.27	27.38

NOTES

1. SEE STREAM PROFILE, SHEET CP1-B.
2. SEE STREAM SECTIONS, SHEET CD1-B.
3. SEE LWM, SHEET LWM1-B.

US 12 MP 17.56 UNNAMED
TRIBUTARY TO WENZEL SLOUGH

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DESIGNED BY	K. COMINGS
ENTERED BY	D. HENNINGS
CHECKED BY	G. RAND
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State
Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PLAN

PLAN REF NO CR2-B

SHEET OF SHEETS

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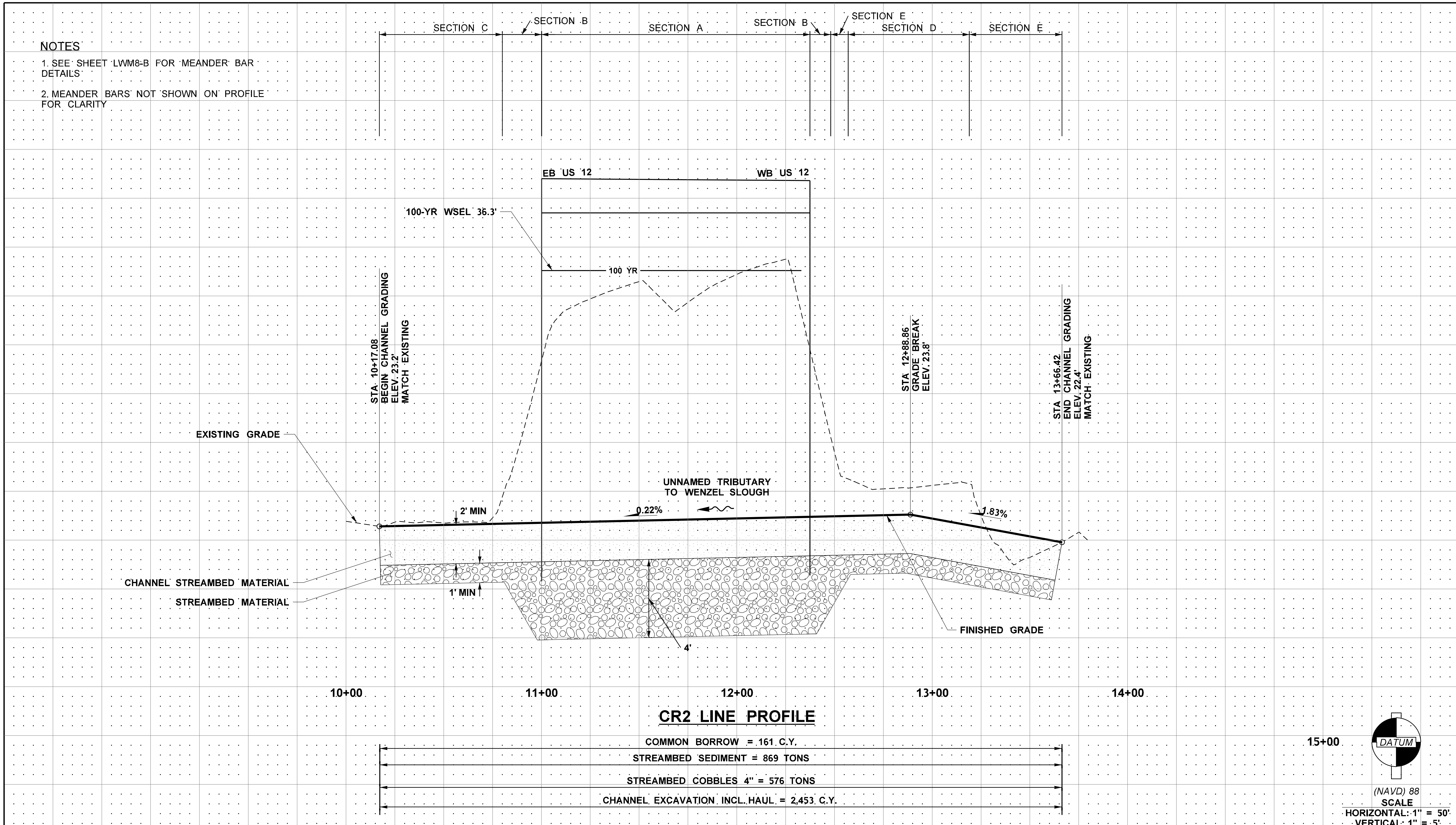

CR2 LINE PROFILE

COMMON BORROW = 161 C.Y.
STREAMBED SEDIMENT = 869 TONS
STREAMBED COBBLES 4" = 576 TONS
CHANNEL EXCAVATION INCL. HAUL = 2,453 C.Y.

(NAVD) 88
SCALE
HORIZONTAL: 1" = 50'
VERTICAL: 1" = 5'

pw:\\HOOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\17.56_TribToWenzelSlough\Design_CAD_Sheets\Preliminary_Design\US12MP17.56_E_PR_CR_001.dgn

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

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DATE	10/26/2022			
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DESIGNED BY	K. COMINGS			
ENTERED BY	R. WILCOX			
CHECKED BY	J. GAGE			
PROJ. ENGR.	B. ELLIOTT			
REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001
JOB NUMBER 21C522
CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE
P.E. STAMP BOX DATE

Washington State Department of Transportation
DAVID EVANS AND ASSOCIATES INC.

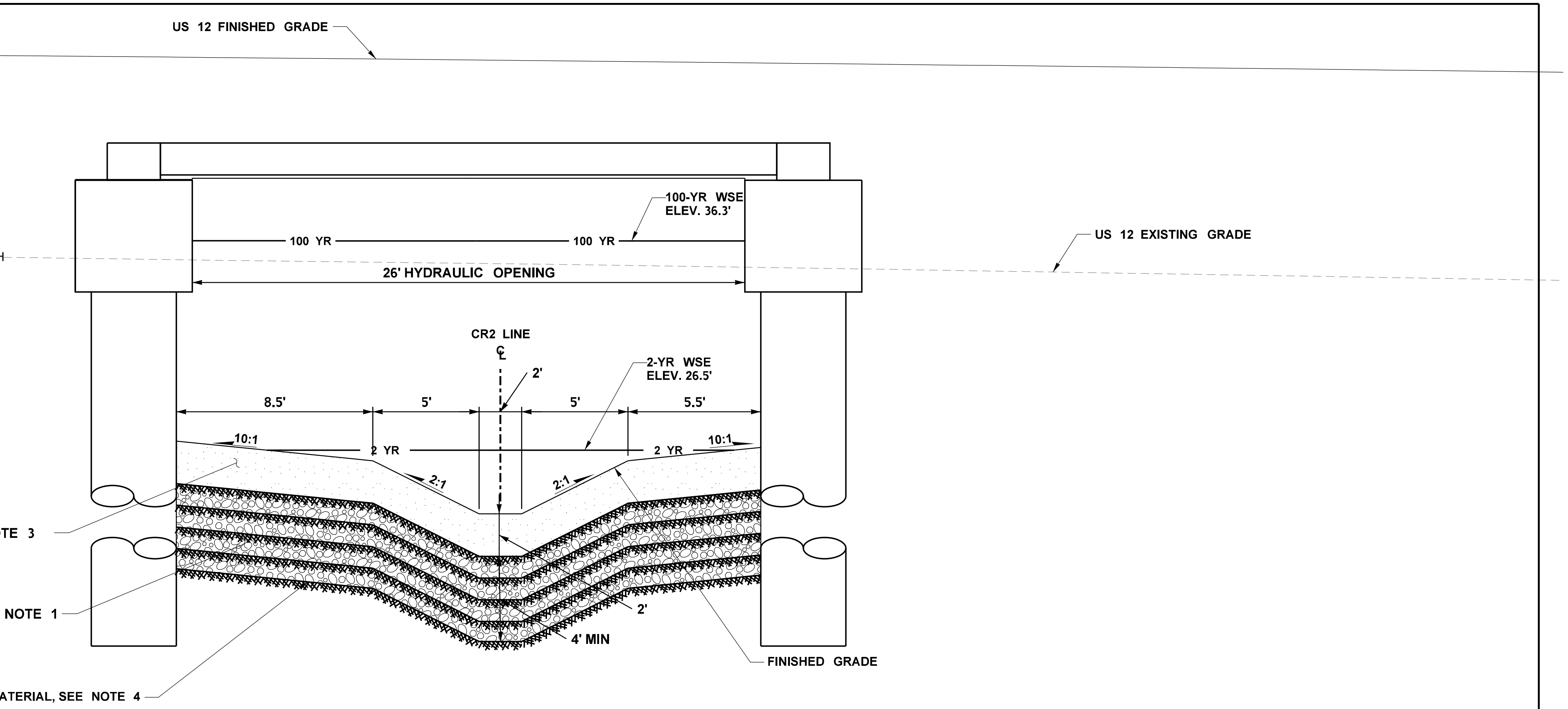
US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM PROFILE

PLAN REF. NO. CP1-B
SHEET OF SHEETS

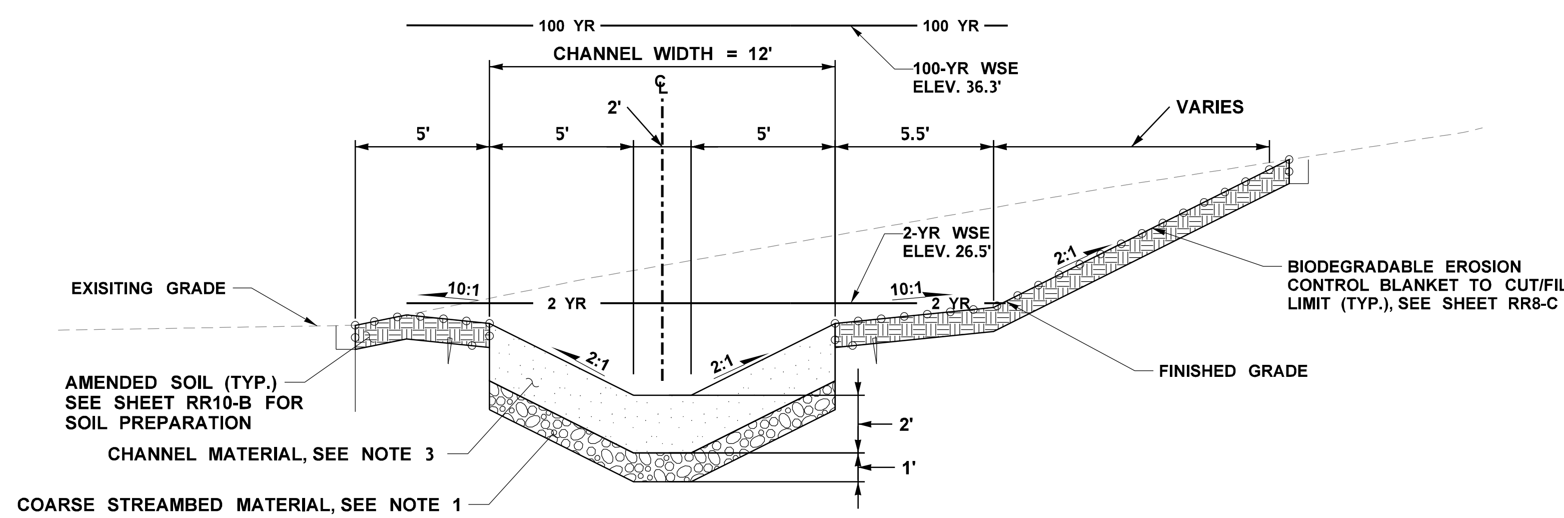
NOTES

1. COARSE STREAMBED MATERIAL SHALL CONSIST OF 60 PERCENT 4" COBBLE (9-03.11(2)) AND 40 PERCENT STREAMBED SEDIMENT (9-03.11(1)). STREAMBED SEDIMENT SHALL BE INSTALLED IN 1' LIFTS WITH A LAYER OF SLASH BELOW AND ABOVE EACH LIFT.
2. A 3' MINIMUM FREEBOARD IS REQUIRED ABOVE THE 100-YEAR FLOOD WSE FROM THE CHEHALIS RIVER BACKWATER.
3. CHANNEL MATERIAL SHALL CONSIST OF 100 PERCENT STREAMBED SEDIMENT (9.03.11(1))).
4. SLASH MATERIAL SHALL CONSIST OF SMALL LOGS OR BRANCHES THAT HAVE A MAXIMUM DIAMETER OF 4 INCHES AND A MAXIMUM LENGTH OF 6 FEET. SEE SHEET LWM9-B FOR SLASH PLACEMENT DETAILS.



SECTION A - SECANT PILE BURIED STRUCTURE

CR2 11+00.09 TO CR2 12+37.43
NTS



SECTION B - TYPICAL OPEN CHANNEL

CR2 10+80.00 TO CR2 11+00.09
CR2 12+37.43 TO CR2 12+48.00
NTS

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

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TIME	10:04:16 AM
DATE	10/26/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM DETAILS

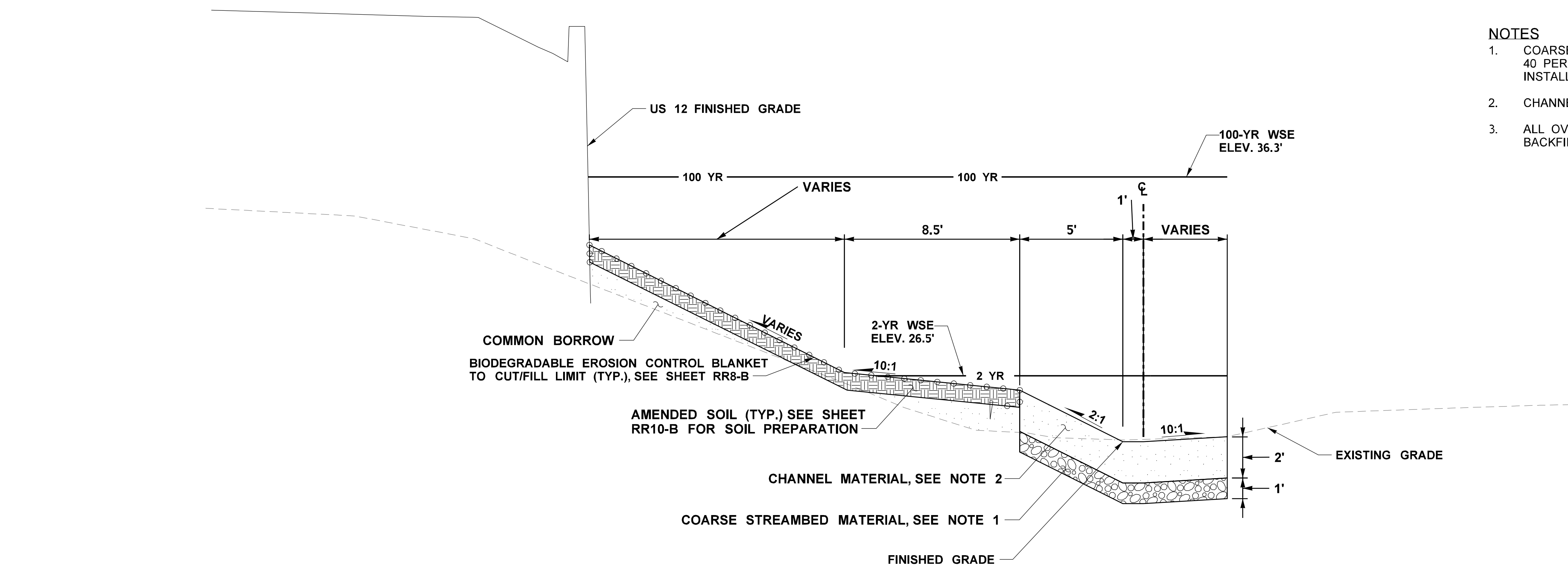
PLAN REF NO CD1-B

SHEET OF SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\17.56_TribToWenzelSlough\Design_CAD_Sheets\Preliminary_Design\US12MP17.56_E_DE_CR_001.dgn pw:\\HQOLYMAPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\17.56_TribToWenzelSlough\Design_CAD_Sheets\Preliminary_Design\US12MP17.56_E_DE_CR_002.dgn

NOTES

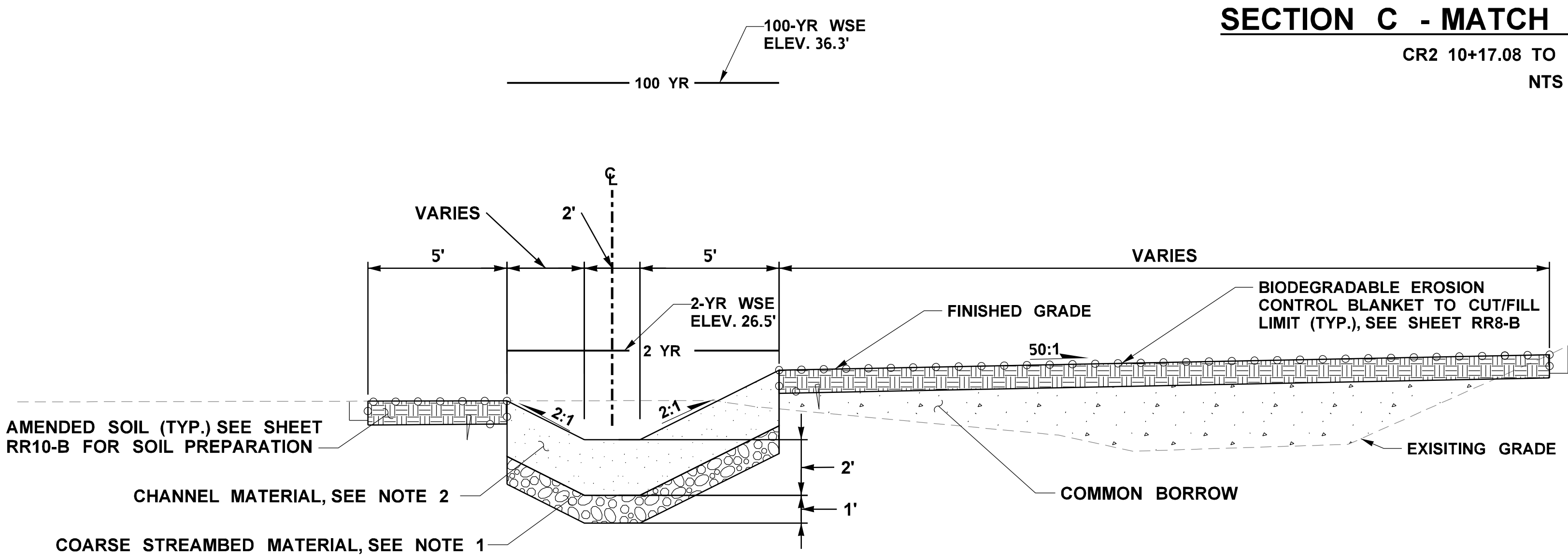
1. COARSE STREAMBED MATERIAL SHALL CONSIST OF 60 PERCENT 4" COBBLE (9-03.11(2)) AND 40 PERCENT STREAMBED SEDIMENT (9-03.11(1)). STREAMBED SEDIMENT SHALL BE INSTALLED IN 1' LIFTS WITH A LAYER OF SLASH BELOW AND ABOVE EACH LIFT.
2. CHANNEL MATERIAL SHALL CONSIST OF 100 PERCENT STREAMBED SEDIMENT (9.03.11(1))).
3. ALL OVEREXCAVATION REQUIRED FOR STREAMBED MATERIAL INSTALLATION SHALL BE BACKFILLED WITH NATIVE MATERIAL.



SECTION C - MATCH EXISTING SECTION

CR2 10+17.08 TO CR2 10+80.00

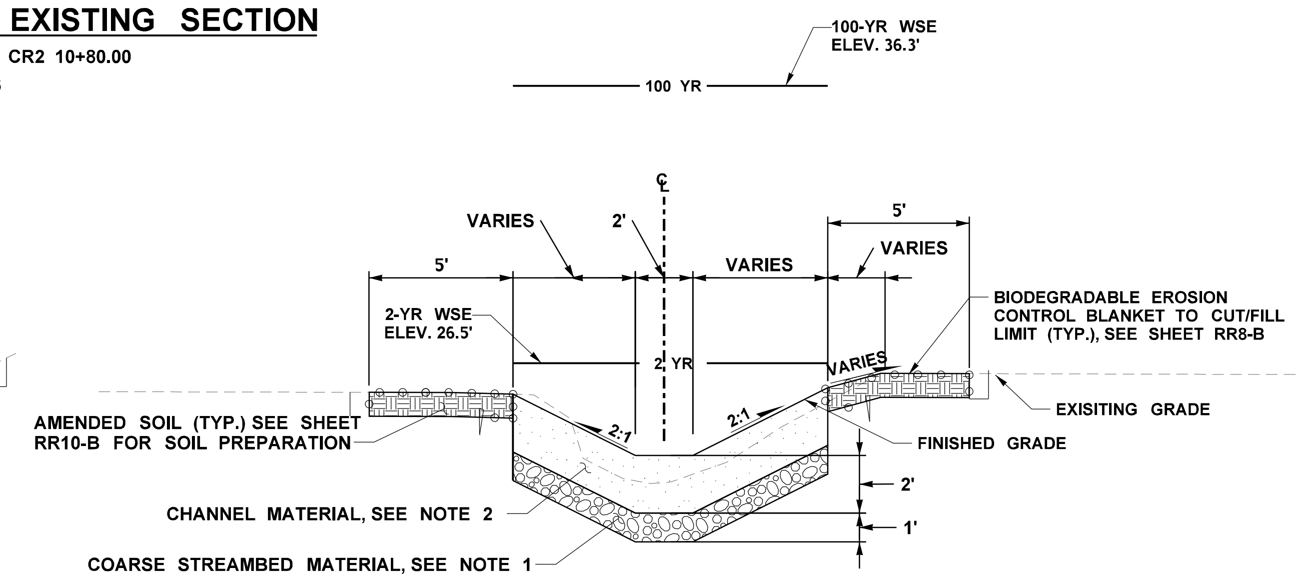
NTS



SECTION D - TYPICAL OPEN CHANNEL FILLING EXISTING CHANNEL

CR2 12+57.00 TO CR2 13+19.00

NTS



SECTION E - TYPICAL OPEN CHANNEL UPSTREAM

CR2 12+48.00 TO CR2 12+57.00
CR2 13+19.00 TO CR2 13+66.42

NTS

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

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DATE	10/26/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 & SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

STREAM DETAILS

PLAN REF NO CD2-B

SHEET OF SHEETS

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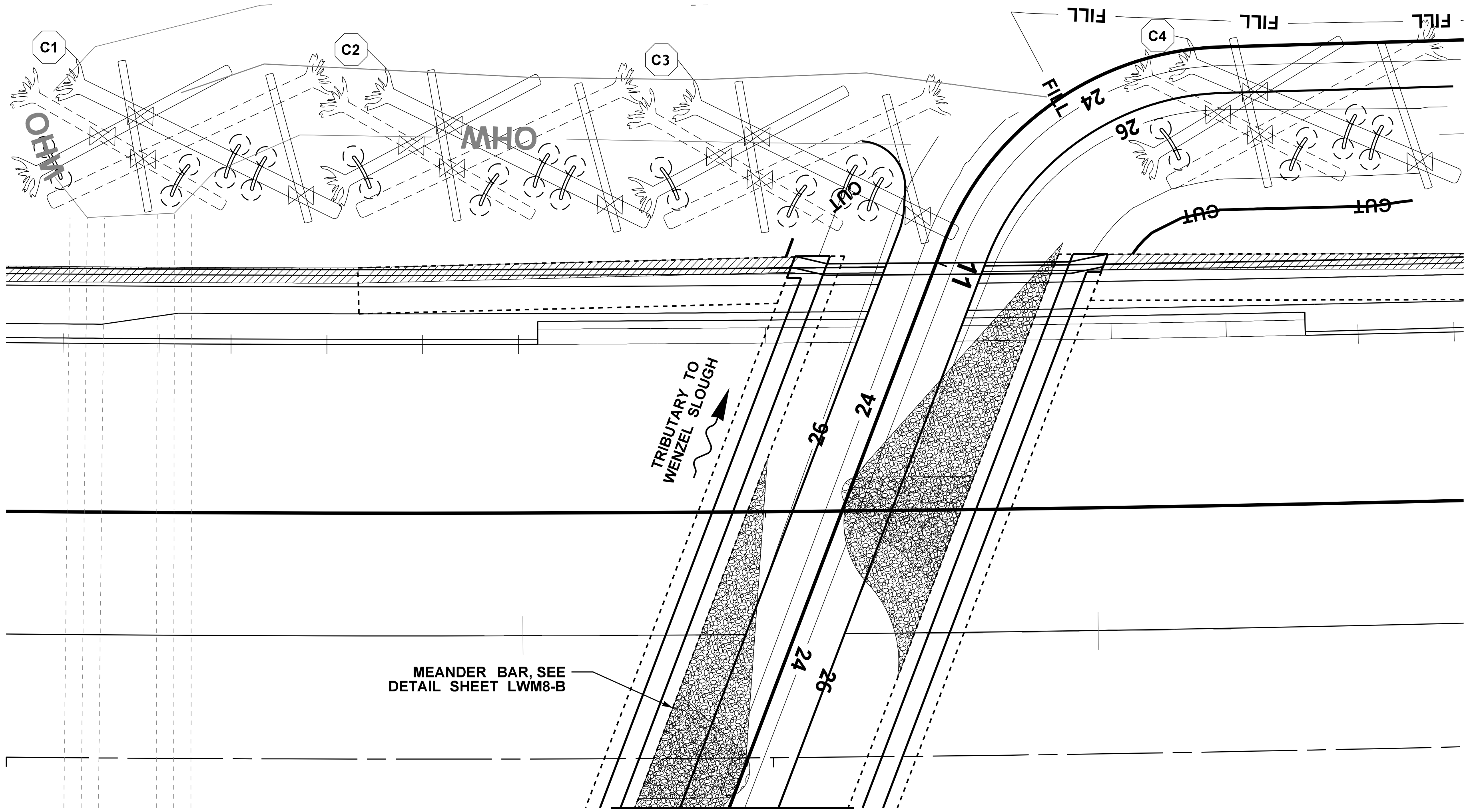


LARGE WOODY MATERIAL - DOWNSTREAM END

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD (8 TOTAL)

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD (8 TOTAL)

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD (8 TOTAL)

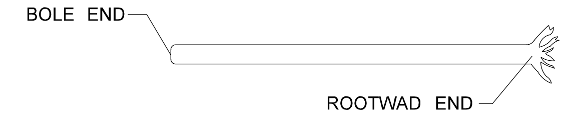
ROCK COLLAR - 3-MAN BOULDER (32 TOTAL BOULDERS), SEE SHEET LWM7-B

CABLE LASHING, SEE SHEET LWM6-B

CLUSTER ID, SEE SHEETS LWM3-B, LWM4-B, AND LWM5-B

NOTES:

1. DASHED LINES INDICATE BURIED LOGS.
2. SEE SHEETS LWM3-B, LWM4-B, AND LWM5-B FOR LOG ID NUMBERS.
3. LOCATIONS AND ORIENTATIONS OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE DIRECTED BY THE ENGINEER IN THE FIELD. SEE SPECIAL PROVISION "LARGE WOODY MATERIAL (LWM) STRUCTURES".
4. 100-YR WSEL: 36.3'



0 10 20
SCALE IN FEET

N

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
C1	1	11+21.6	75.0' RT	11+18.0	112.5' RT	SEE SHEET LWM5-C
C1	2	11+09.1	95.0' RT	11+30.8	114.0' RT	SEE SHEET LWM5-C
C1	3	11+26.0	89.4' RT	11+21.3	117.8' RT	SEE SHEET LWM5-C
C1	4	11+33.7	110.9' RT	11+06.4	84.6' RT	SEE SHEET LWM5-C
C1	5	11+30.3	98.5' RT	11+13.0	108.5' RT	SEE SHEET LWM5-C
C1	6	11+24.1	78.4' RT	11+07.9	90.0' RT	SEE SHEET LWM5-C
C2	1	11+08.4	36.9' RT	11+04.9	74.3' RT	SEE SHEET LWM5-C
C2	2	10+96.9	56.9' RT	11+17.5	75.8' RT	SEE SHEET LWM5-C
C2	3	11+12.9	51.3' RT	11+08.2	79.5' RT	SEE SHEET LWM5-C
C2	4	11+20.7	72.58' RT	10+95.6	46.6' RT	SEE SHEET LWM5-C
C2	5	11+17.1	60.3' RT	11+00.0	70.5' RT	SEE SHEET LWM5-C
C2	6	11+11.0	40.3' RT	10+96.3	52.0' RT	SEE SHEET LWM5-C

		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
C3	1	10+95.6	1.1' LT	10+94.7	36.6' RT	SEE SHEET LWM5-C
C3	2	10+87.9	20.6' RT	11+04.8	38.1' RT	SEE SHEET LWM5-C
C3	3	11+00.0	13.3' RT	10+96.5	41.6' RT	SEE SHEET LWM5-C
C3	4	11+07.7	34.8' RT	10+84.1	11.2' RT	SEE SHEET LWM5-C
C3	5	11+04.3	22.3' RT	10+91.9	33.3' RT	SEE SHEET LWM5-C
C3	6	10+98.1	2.2' RT	10+86.2	16.2' RT	SEE SHEET LWM5-C
C4	1	10+14.3	17.5' LT	10+53.9	2.2' LT	SEE SHEET LWM5-C
C4	2	10+34.6	0.4' RT	10+64.0	12.2' LT	SEE SHEET LWM5-C
C4	3	10+34.8	17.5' LT	10+61.1	2.2' LT	SEE SHEET LWM5-C
C4	4	10+63.0	16.5' LT	10+24.1	0.6' LT	SEE SHEET LWM5-C
C4	5	10+44.7	18.4' LT	10+48.9	1.1' RT	SEE SHEET LWM5-C
C4	6	10+23.7	19.2' LT	10+29.5	0.0' LT	SEE SHEET LWM5-C

LEGEND

21 NEW STREAM ALIGNMENT

NEW STRUCTURE

STREAM SLOPE BANK

OHW ORDINARY HIGH WATER

CUT FILL LIMITS OF EARTHWORK

286 HIGHWAY ALIGNMENT

INTERMEDIATE CONTOUR

EDGE OF PAVEMENT

EXISTING DITCH

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

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DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

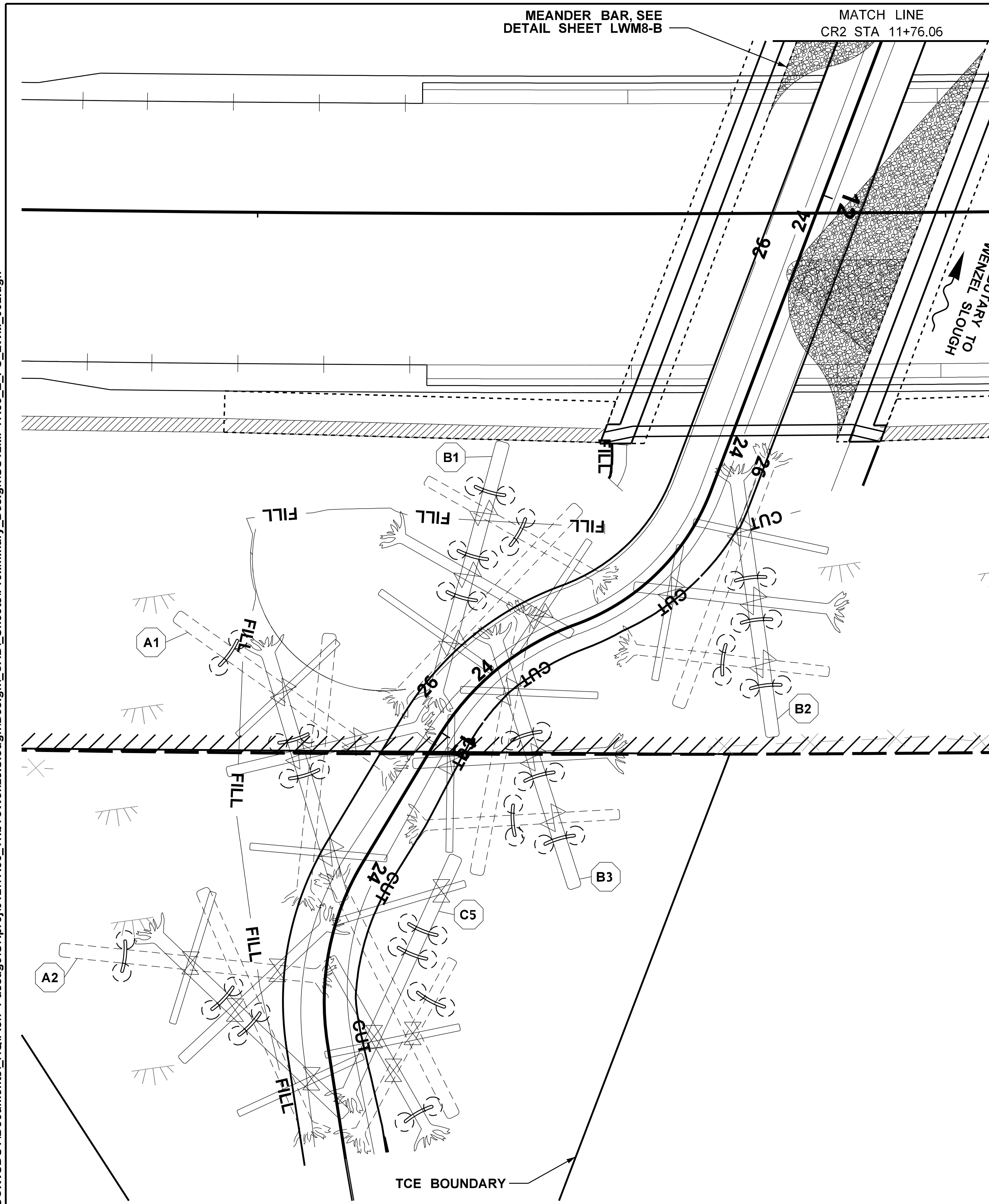
DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

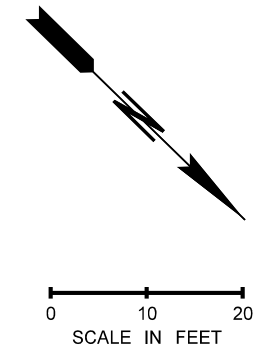
LARGE WOODY MATERIAL PLAN

PLAN REF NO LWM1-B

SHEET OF SHEETS



LARGE WOODY MATERIAL - UPSTREAM END



LEGEND

21	NEW STREAM ALIGNMENT
	NEW STRUCTURE
	STREAM SLOPE BANK
OHW	ORDINARY HIGH WATER
CUT FILL	LIMITS OF EARTHWORK
286	HIGHWAY ALIGNMENT
	WSDOT RIGHT OF WAY
	EASEMENT LINE
	EDGE OF PAVEMENT
	EXISTING DITCH
WB	WETLAND

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD (14 TOTAL)

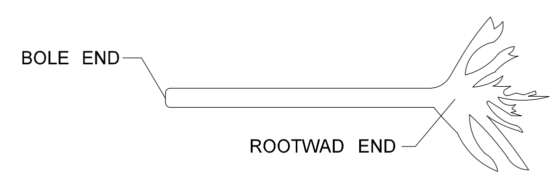
18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD (10 TOTAL)

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD (12 TOTAL)

ROCK COLLAR - 3-MAN BOULDER (44 TOTAL BOULDERS), SEE SHEET LWM7-B

CABLE LASHING, SEE SHEET LWM6-B

CLUSTER ID, SEE SHEETS LWM3-B, LWM4-B, AND LWM5-B



		BOLE		ROOTWAD		
CLUSTER ID	LOG ID	STATION	OFFSET	STATION	OFFSET	NOTES
B1	1	12+75.4	1.2' LT	12+86.8	23.6' RT	SEE SHEET LWM4-C
B1	2	12+75.0	28.5' RT	12+96.3	3.6' RT	SEE SHEET LWM4-C
B1	3	12+82.2	28.6' RT	12+68.2	4.7' RT	SEE SHEET LWM4-C
B1	4	12+62.8	14.4' RT	12+99.0	7.8' RT	SEE SHEET LWM4-C
B1	5	12+65.7	9.9' RT	12+84.6	0.3' RT	SEE SHEET LWM4-C
B1	6	12+91.8	19.7' RT	12+88.4	0.3' RT	SEE SHEET LWM4-C
B2	1	12+64.3	0.7' RT	12+51.9	23.3' LT	SEE SHEET LWM4-C
B2	2	12+62.8	29.1' LT	12+43.3	3.2' LT	SEE SHEET LWM4-C
B2	3	12+56.1	28.2' LT	12+69.2	6.5' LT	SEE SHEET LWM4-C
B2	4	12+68.0	17.4' LT	12+39.4	6.4' LT	SEE SHEET LWM4-C
B2	5	12+68.5	12.4' LT	12+55.1	0.2' RT	SEE SHEET LWM4-C
B2	6	12+47.3	19.1' LT	12+51.1	0.3' RT	SEE SHEET LWM4-C
B3	1	13+06.1	1.3' RT	12+78.1	19.4' LT	SEE SHEET LWM4-C
B3	2	13+09.2	28.5' LT	12+85.4	3.4' RT	SEE SHEET LWM4-C
B3	3	12+86.8	27.8' LT	13+13.2	4.4' LT	SEE SHEET LWM4-C
B3	4	13+15.1	14.9' LT	12+81.0	3.5' RT	SEE SHEET LWM4-C
B3	5	13+14.2	9.9' LT	12+97.1	0.2' RT	SEE SHEET LWM4-C
B3	6	12+74.2	10.8' LT	12+93.5	1.5' RT	SEE SHEET LWM4-C
A1	1	13+21.1	23.6' RT	13+00.8	3.1' RT	SEE SHEET LWM3-C
A1	2	13+28.4	0.1' RT	13+03.4	27.4' RT	SEE SHEET LWM3-C
A1	3	13+05.3	41.6' RT	13+08.4	3.8' RT	SEE SHEET LWM3-C
A1	4	12+97.9	21.6' RT	13+29.3	6.0' RT	SEE SHEET LWM3-C
A1	5	13+15.7	25.0' RT	12+98.0	19.7' RT	SEE SHEET LWM3-C
A1	6	13+26.7	15.6' RT	13+19.8	2.8' LT	SEE SHEET LWM3-C
C5	1	13+14.1	11.1' LT	13+56.6	2.3' LT	SEE SHEET LWM5-C
C5	2	13+36.8	0.4' LT	13+64.0	12.4' LT	SEE SHEET LWM5-C
C5	3	13+31.7	17.9' LT	13+63.2	2.2' LT	SEE SHEET LWM5-C
C5	4	13+62.7	16.8' LT	13+26.7	1.5' RT	SEE SHEET LWM5-C
C5	5	13+50.1	19.4' LT	13+51.1	0.6' RT	SEE SHEET LWM5-C
C5	6	13+16.9	14.4' LT	13+31.8	0.4' RT	SEE SHEET LWM5-C
A2	1	13+48.9	21.3' RT	13+32.4	1.2' RT	SEE SHEET LWM3-C
A2	2	13+60.1	1.0' LT	13+37.6	24.9' RT	SEE SHEET LWM3-C
A2	3	13+39.7	38.8' RT	13+39.7	0.7' RT	SEE SHEET LWM3-C
A2	4	13+32.4	20.1' RT	13+61.2	4.6' RT	SEE SHEET LWM3-C
A2	5	13+45.4	22.1' RT	13+32.3	18.5' RT	SEE SHEET LWM3-C
A2	6	13+57.8	14.3' RT	13+52.0	5.0' LT	SEE SHEET LWM3-C

NOTES:

1. DASHED LINES INDICATE BURIED LOGS.
2. SEE SHEETS LWM3-B, LWM4-B, AND LWM5-B FOR LOG ID NUMBERS.
3. LOCATIONS AND ORIENTATIONS OF LARGE WOODY MATERIAL (LWM) STRUCTURES AS SHOWN ON THIS SHEET ARE APPROXIMATE AND WILL BE DIRECTED BY THE ENGINEER IN THE FIELD. SEE SPECIAL PROVISION "LARGE WOODY MATERIAL (LWM) STRUCTURES".
4. 100-YR WSEL: 36.3'

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

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DATE	10/26/2022
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DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

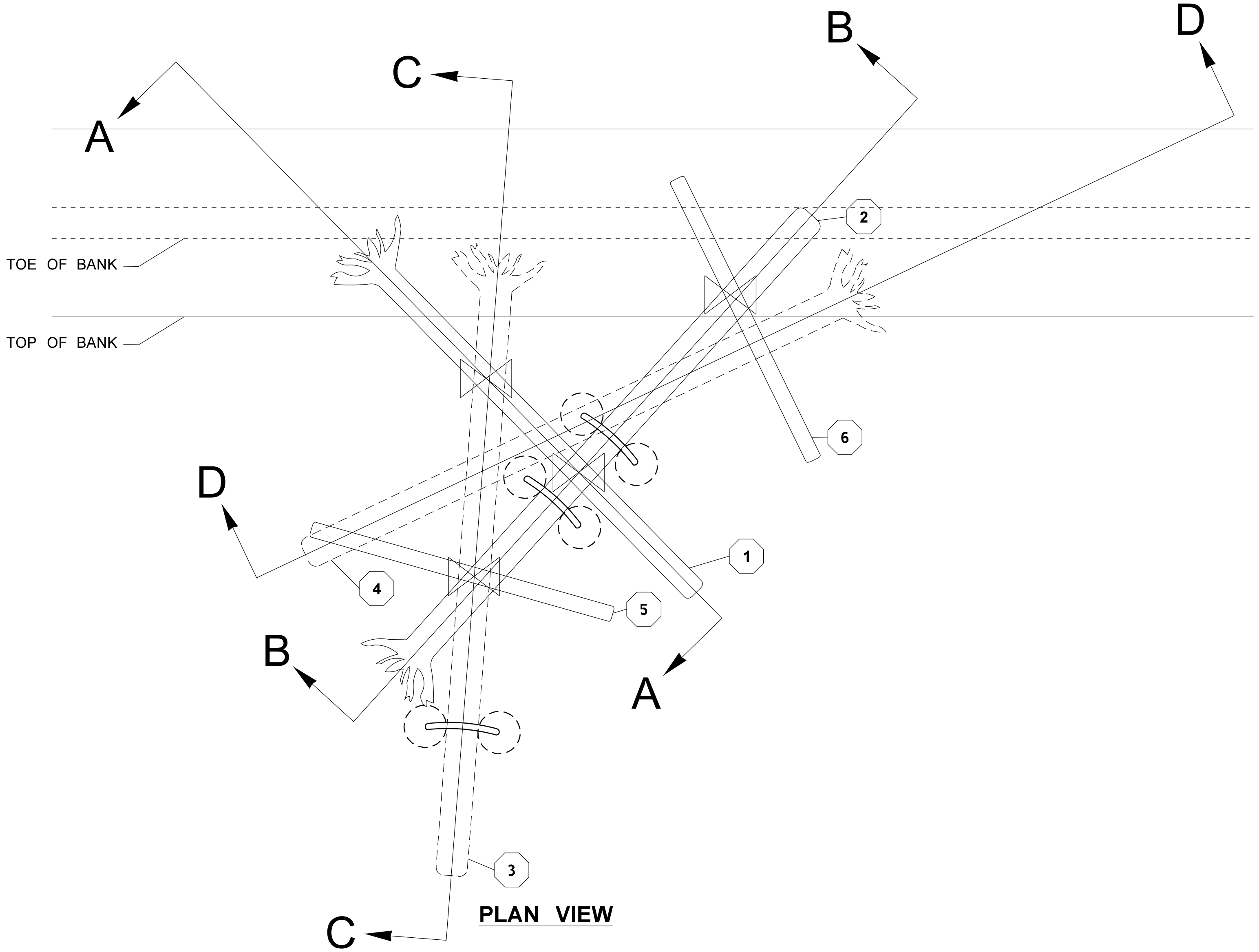
DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL PLAN

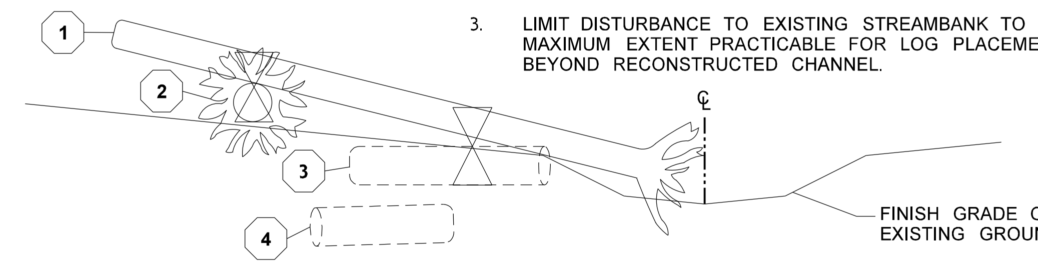
PLAN REF NO LWM2-B

SHEET OF SHEETS

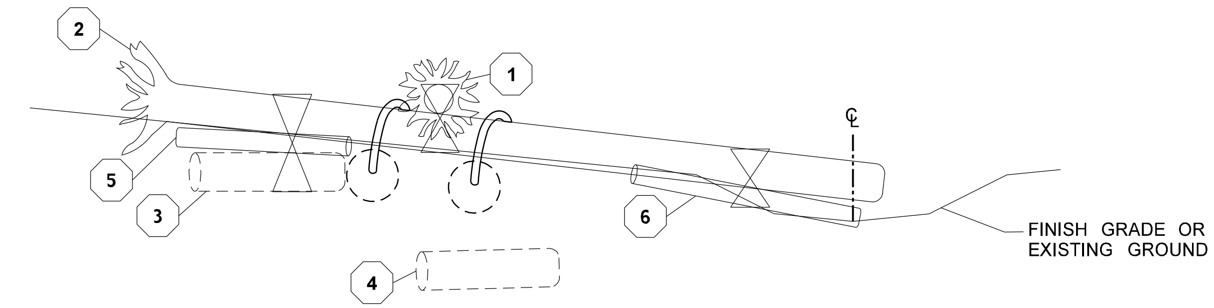


PLAN VIEW

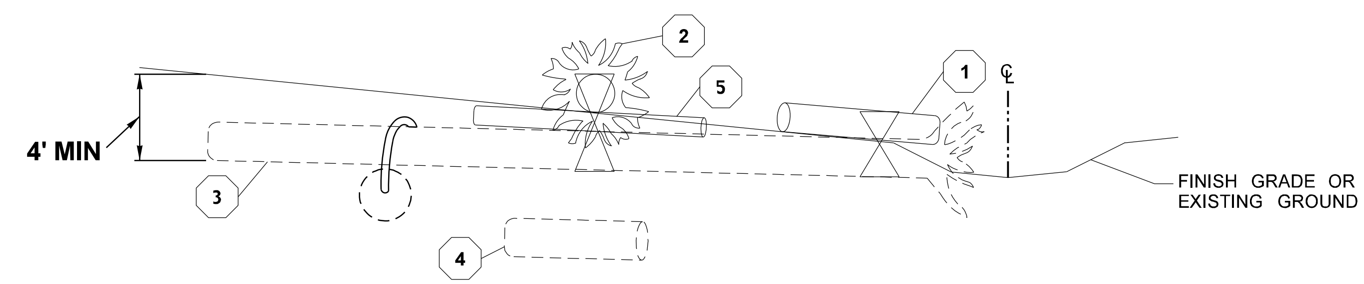
NOTES:
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



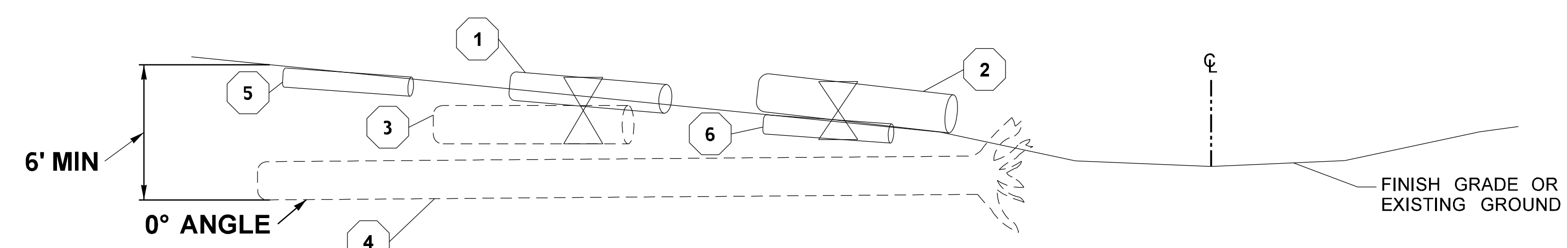
SECTION A - ANCHORED SURFACE LOGS



SECTION B - ANCHORED SURFACE LOGS



SECTION C - ANCHORED SURFACE LOGS



SECTION D - BURIED LOG

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD

ROCK COLLAR - 3-MAN BOULDER, SEE SHEET LWM7-B

CABLE LASHING, SEE SHEET LWM6-B

LARGE WOOD CLUSTER TYPE A

NTS

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

FILE NAME	c:\users\rhw\pw_wsdot\d0354378\US12MP17.56_E_DE_LWM_001.dgn
TIME	10:04:26 AM
DATE	10/26/2022
PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

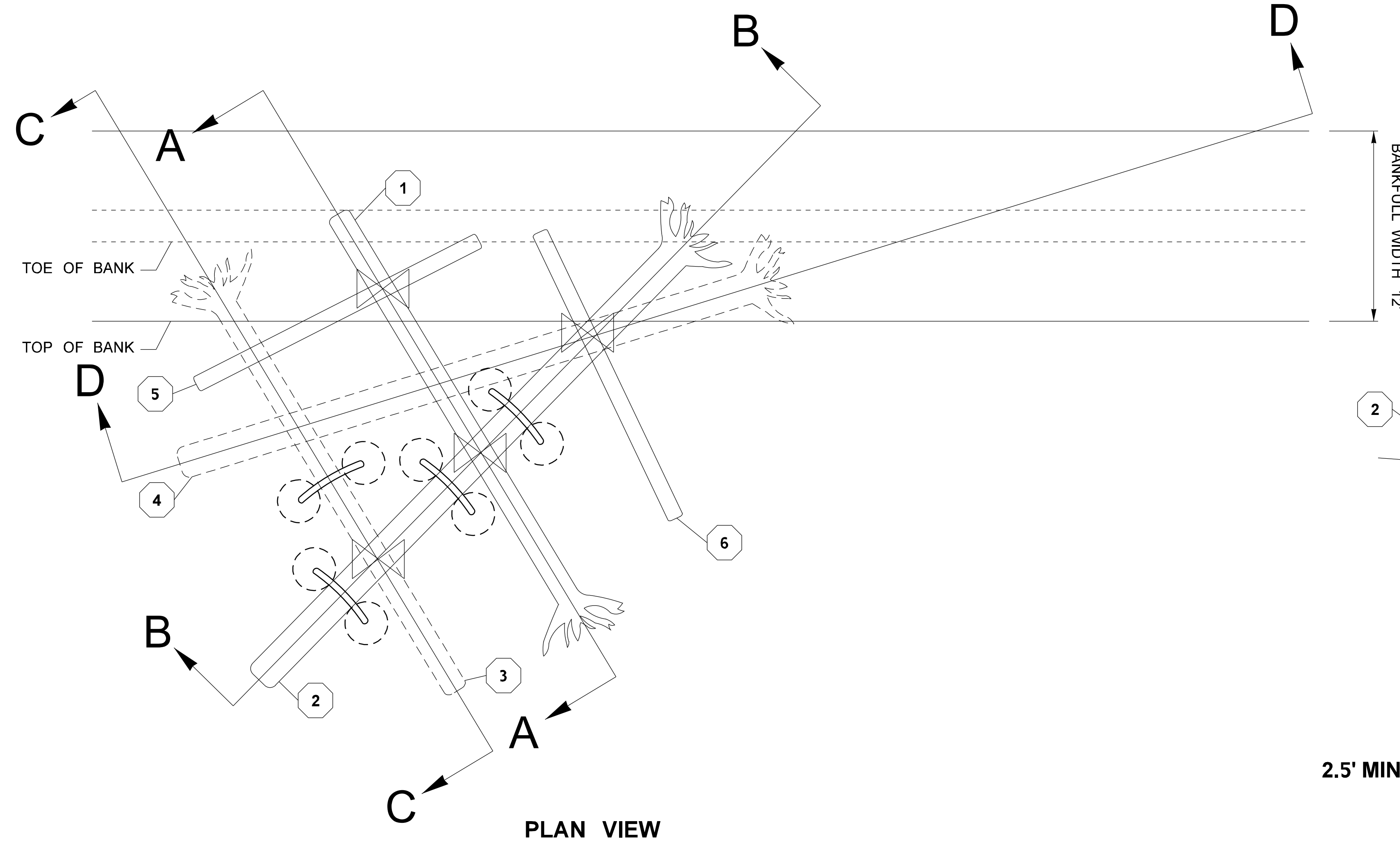
PLAN REF NO LWM3-B

SHEET OF SHEETS

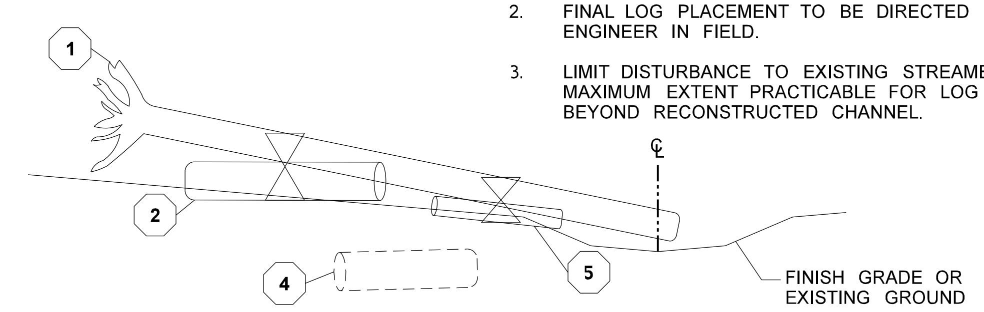
pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\012\17.56_TribToWenzelSlough\Design_CAD_Sheets\Preliminary_Design\US12MP17.56_E_DE_LWM_001.dgn

NOTES:

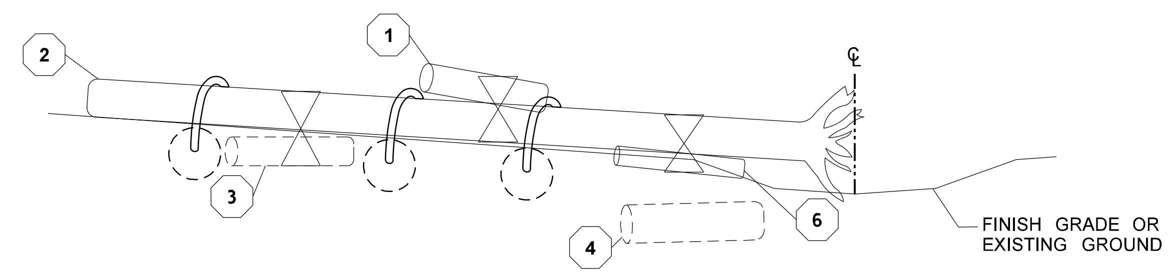
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT TO BE DIRECTED BY ENGINEER IN FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



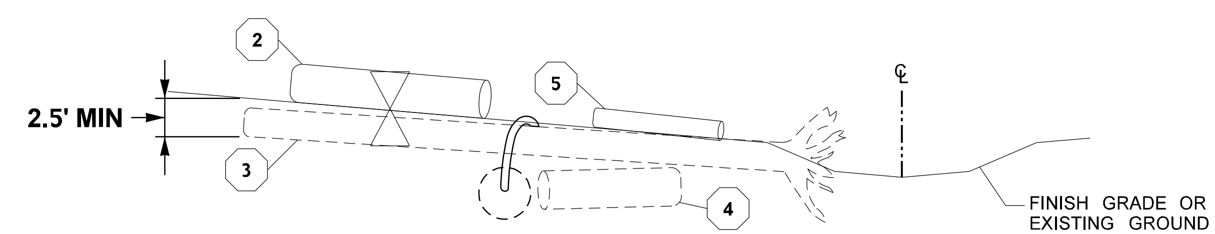
PLAN VIEW



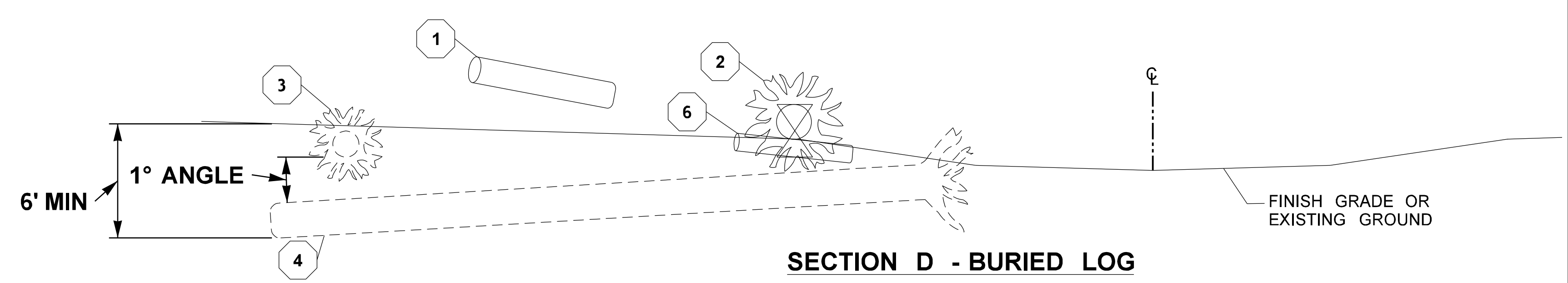
SECTION A - ANCHORED SURFACE LOGS



SECTION B - ANCHORED SURFACE LOGS



SECTION C - ANCHORED SURFACE LOGS



SECTION D - BURIED LOG

LEGEND

24" MIN DIA. 40' MIN. LENGTH, WITH ROOTWAD

18" MIN DIA. 30' MIN. LENGTH, WITH ROOTWAD

12" MIN DIA. 20' MIN. LENGTH, WITHOUT ROOTWAD

ROCK COLLAR - 3-MAN BOULDER, SEE SHEET LWM7-B

CABLE LASHING, SEE SHEET LWM6-B

LARGE WOOD CLUSTER TYPE B

NTS

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PLOTTED BY	Rhw
DESIGNED BY	K. COMINGS
ENTERED BY	R. WILCOX
CHECKED BY	J. GAGE
PROJ. ENGR.	B. ELLIOTT
REGIONAL ADM.	S. ROARK

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO. ARPA001

JOB NUMBER 21C522

CONTRACT NO. XL6115

LOCATION NO.

P.E. STAMP BOX DATE

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Washington State Department of Transportation

DAVID EVANS AND ASSOCIATES INC.

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM4-B

SHEET OF SHEETS

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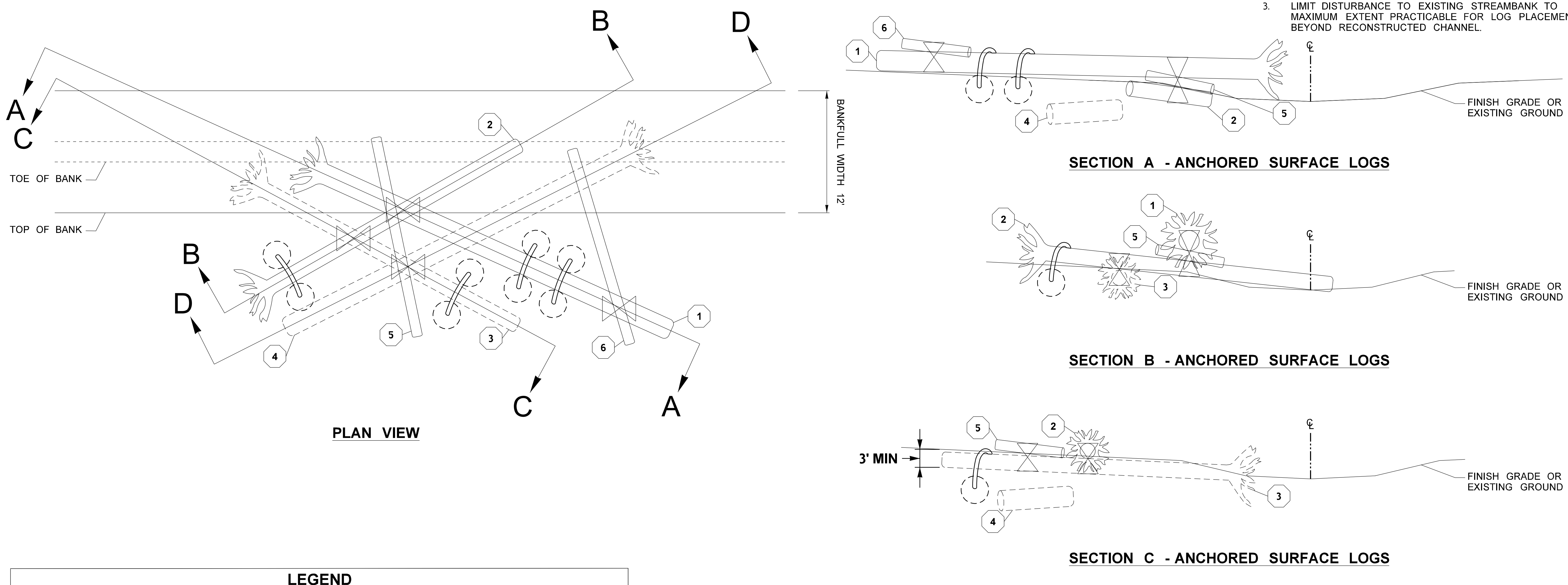
NOTES:
1. DASHED LINES INDICATE BURIED PIECES.
2. FINAL LOG PLACEMENT SUBJECT TO APPROVAL OF ENGINEER IN THE FIELD.
3. LIMIT DISTURBANCE TO EXISTING STREAMBANK TO MAXIMUM EXTENT PRACTICABLE FOR LOG PLACEMENT BEYOND RECONSTRUCTED CHANNEL.



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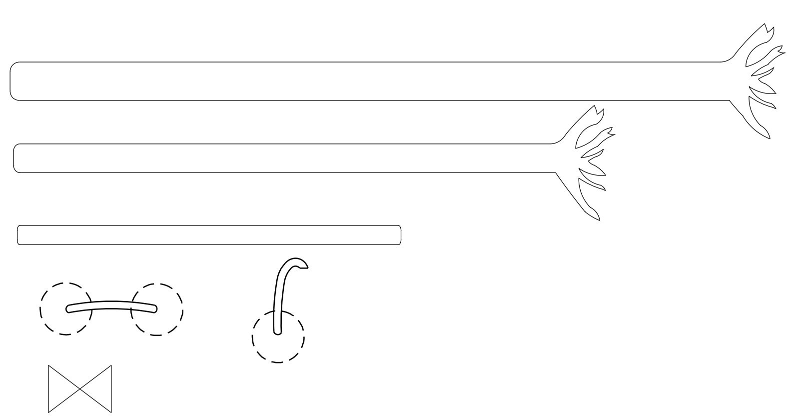

LARGE WOOD CLUSTER TYPE C

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US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

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JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

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LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM5-B

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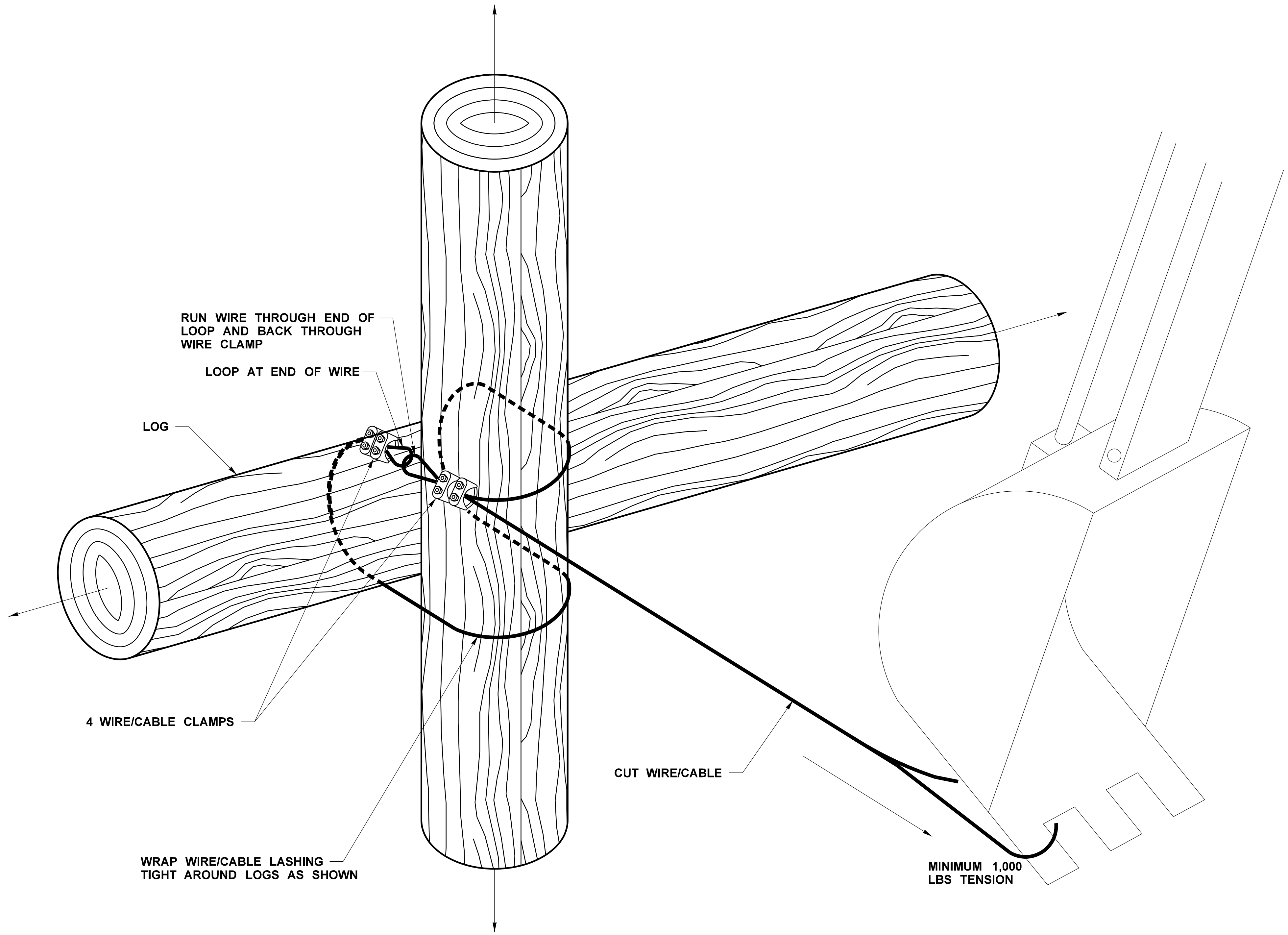

WIRE-ROPE LASHING CONNECTION

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JOB NUMBER 21C522		
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DAVID EVANS AND ASSOCIATES INC.

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

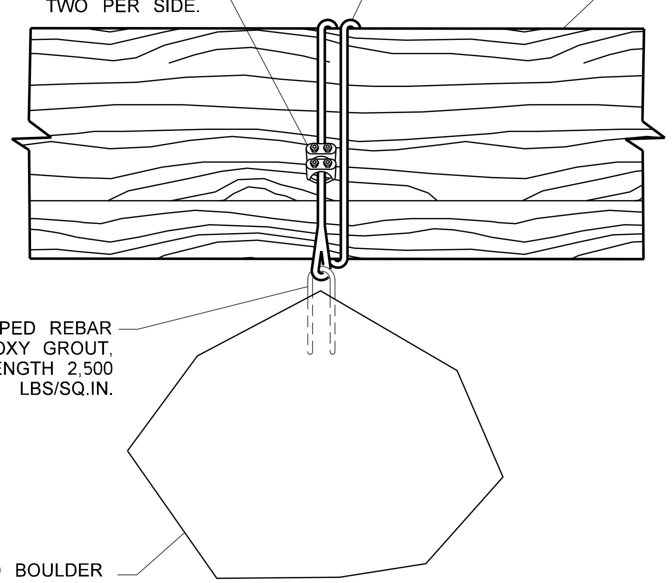
LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM6-B

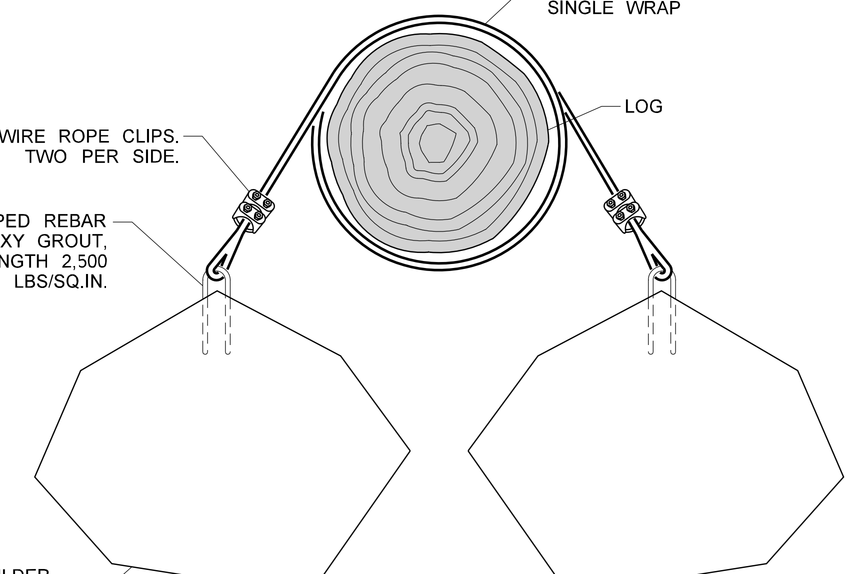
SHEET OF SHEETS

NOTES:

1. ROCK SHALL BE SUFFICIENTLY HARD TO NOT BREAK WHEN UNLOADED FROM THE HAUL VEHICLE AND/OR DROPPED FROM UP TO 8 FT AT THE STAGING AREA. ROCK BROKEN DURING TESTING SHALL BE REJECTED.
2. HOLES DRILLED IN ROCKS MUST BE THOROUGHLY CLEANED OF ALL ROCK POWDER, DIRT, AND DEBRIS PRIOR TO PLACEMENT OF EPOXY.
3. THE WIRE ROPE SHALL BE NON-OILED AND NON-GALVANIZED.
4. BOULDERS SHALL BE FULLY BURIED.



SIDE VIEW



SECTION VIEW

TYPICAL DETAIL ROCK COLLAR

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US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

LARGE WOODY MATERIAL DETAILS

PLAN REF NO LWM7-B

SHEET OF SHEETS

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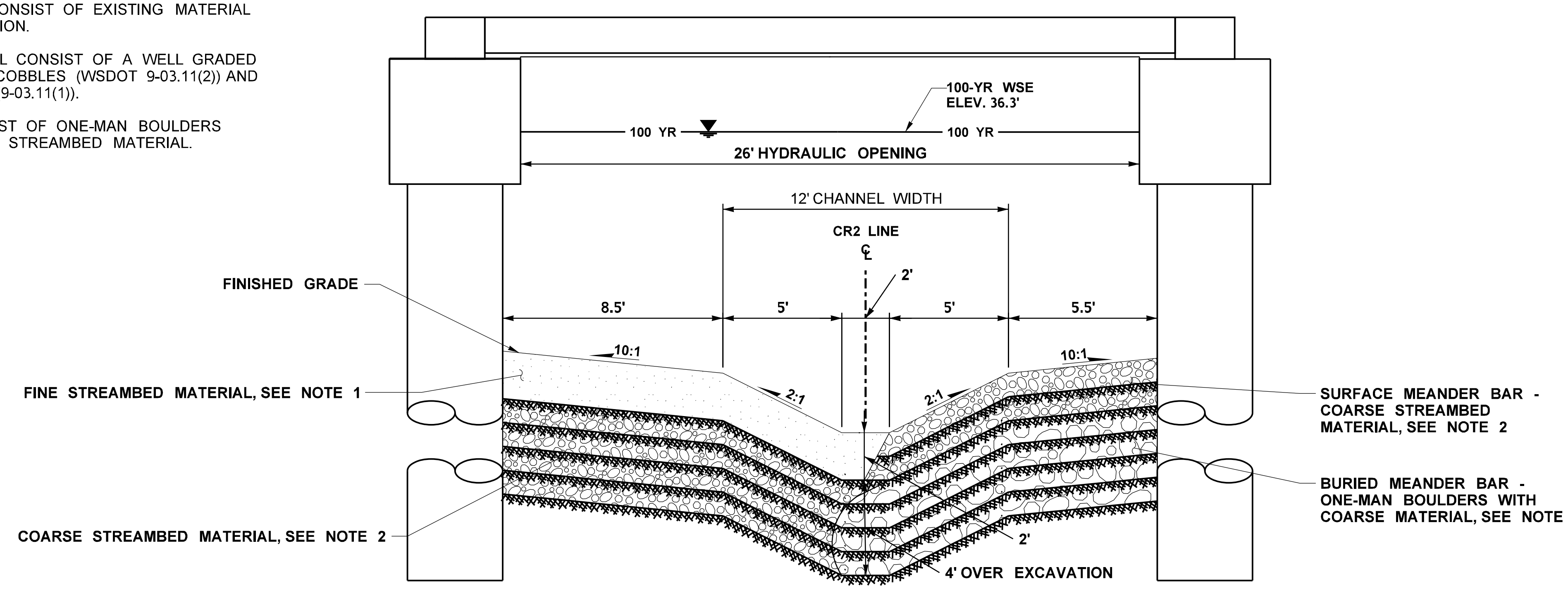
NOTES
1. FINE STREAMBED MATERIAL SHALL CONSIST OF EXISTING MATERIAL RESERVED FROM CHANNEL EXCAVATION.
2. COARSE STREAMBED MATERIAL SHALL CONSIST OF A WELL GRADED MIX OF 60 PERCENT 4" STREAMBED COBBLES (WSDOT 9-03.11(2)) AND 40 PERCENT STREAMBED SEDIMENT (9-03.11(1)).
3. BURIED MEANDER BAR SHALL CONSIST OF ONE-MAN BOULDERS (9-03.11(3)) BACKFILLED WITH COARSE STREAMBED MATERIAL.



MEANDER BAR AND BOULDER ROW

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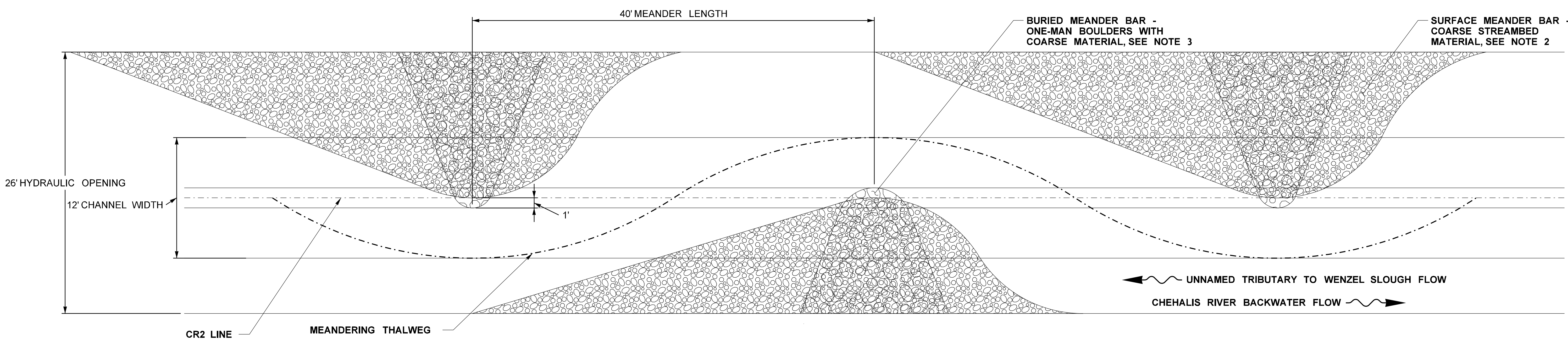

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JOB NUMBER 21C522

CONTRACT NO. XL6115 | LOCATION NO.

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DAVID EVANS AND ASSOCIATES INC.

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

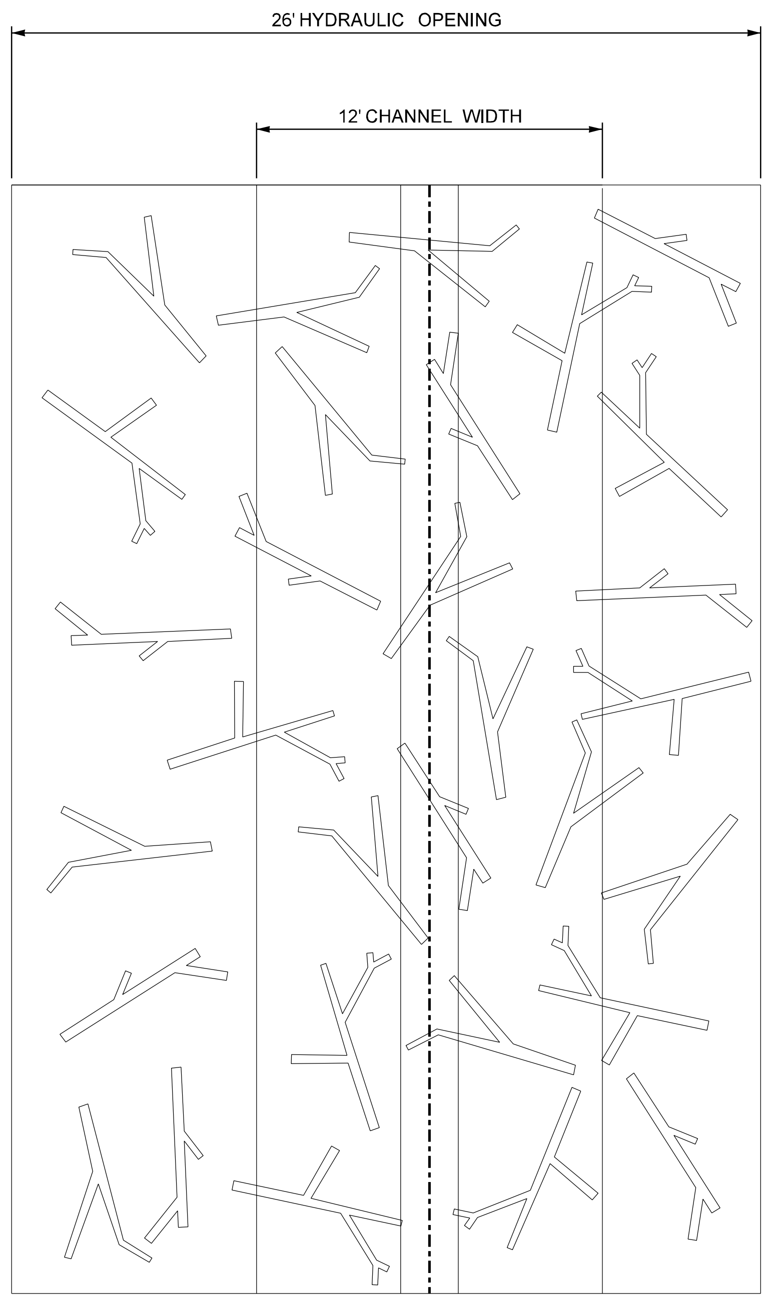
US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

MEANDER BAR DETAILS

PLAN REF NO LWM8-B

SHEET OF SHEETS

NOTES
1. SLASH MATERIAL SHALL CONSIST OF SMALL LOGS OR BRANCHES THAT HAVE A MAXIMUM DIAMETER OF 4 INCHES AND A MAXIMUM LENGTH OF 6 FEET.
2. SLASH SHALL BE INSTALLED AT A DENSITY OF 30 PIECES PER 1000 SQUARE FEET PER LAYER.
3. SLASH IS INTENDED TO PROTRUDE INTO STREAMBED MATERIAL LAYERS ABOVE AND BELOW EACH SLASH LAYER. SLASH MAY NOT EXTEND ABOVE FINISHED GRADE BY MORE THAN 6 INCHES.



PLAN VIEW PER 1000 SQUARE FEET
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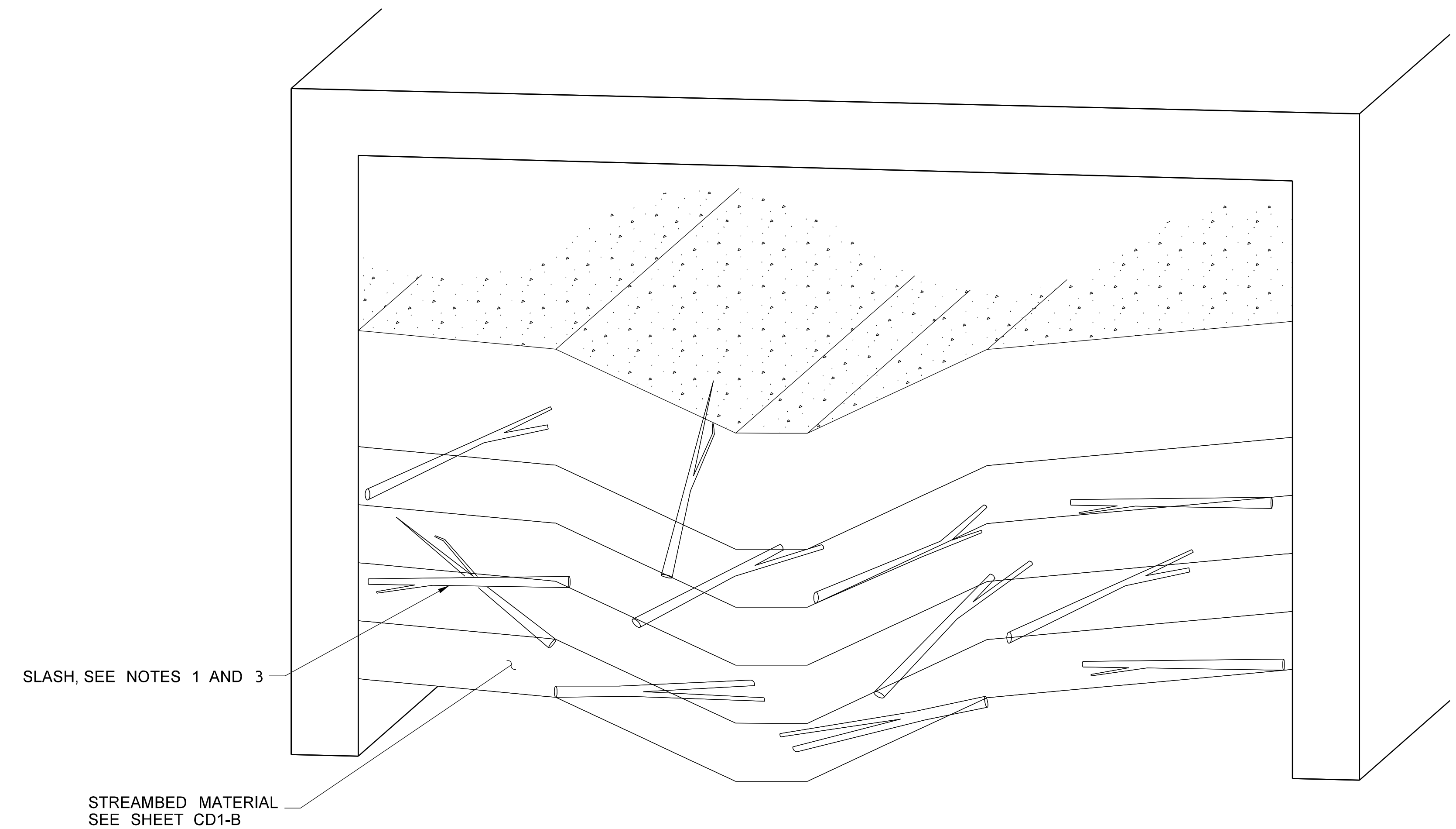

ISOMETRIC VIEW OF SLASH ORIENTATION
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REGIONAL ADM.	S. ROARK	REVISION	DATE	BY

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10	WASH	ARPA001
JOB NUMBER 21C522		
CONTRACT NO. XL6115		LOCATION NO.

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DAVID EVANS AND ASSOCIATES INC.

US 12 MP 17.56 UNNAMED TRIBUTARY TO WENZEL SLOUGH

US 12 AND SR 8
GRAYS HARBOR COUNTY
REMOVE FISH BARRIERS

SLASH DETAILS

PLAN REF NO LWM8-B

SHEET

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Appendix E: Manning’s Calculations (Not Used)

Manning’s n calculations were not required for this project.

Appendix F: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	***US 12***		**Key piece volume**	***1.310***	*yd* ^{3}
Stream name	*Vance*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*349*	*ft*	**Total wood vol./ft**	***0.3948***	*yd* ^{3} */ft stream*
Bankfull width	*12*	*ft*	**Total LWM**[c] **pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Log type	*Diameter at midpoint (ft)*	*Length(ft)* [d]	*Volume (yd* ^{3} */log)* [d]	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd* ^{3} *)*	DBH based on mid point diameter (ft)
A	2.00	*40*	4.65	**yes**	yes	22	102.39	2.19
B	1.50	*30*	1.96	**yes**	yes	18	35.34	1.63
C	1.0	*20*	0.58	**yes**	no	20	11.64	1.06
D	0.3	*6*	0.02	**no**	no	550	10.67	0.38
E			0.00				0.00	
F			0.00				0.00	
G			0.00				0.00	
H			0.00				0.00	
I			0.00				0.00	
J			0.00				0.00	
K			0.00				0.00	
L			0.00				0.00	
M			0.00				0.00	
N			0.00				0.00	
O			0.00				0.00	
P			0.00				0.00	

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	40	610	160.0
Targets	**12**	**40**	**137.8**

US 12 Unnamed Tributary to Wenzel Slough

Large Wood Structure Stability Analysis

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	Sheet
Factors of Safety and Design Constants	2
Hydrologic and Hydraulic Inputs	3
Stream Bed Substrate Properties	4
Bank Soil Properties	5
Wood Properties	6
Cluster Type A	7 - 19
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Cluster Type C	33 - 45
Notation and List of Symbols	46 - 47

Date of Last Revision: September 20, 2022

Designer:
Roxanne Wilcox

Reviewed by:
Karen Comings, P.E.

Large Wood Structure Stability Analysis Spreadsheet was developed by Michael Rafferty, P.E.
Version 1.1

Reference for Companion Paper:

Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center.

US 12 Unnamed Tributary to Wenzel Slough
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

Symbol	Description	Value
FS_V	Factor of Safety for Vertical Force Balance	**1.50**
FS_H	Factor of Safety for Horizontal Force Balance	**1.50**
FS_M	Factor of Safety for Moment Force Balance	**1.50**

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	3.00
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.50
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

US 12 Unnamed Tributary to Wenzel Slough
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 Chehlais yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
Wenzel	10+25	507	12.95	1.84	24.8	525	40

US 12 Unnamed Tributary to Wenzel Slou
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
Wenzel	10+25	**35.81**	Very coarse gravel	5	129.0	80.3	40

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

US 12 Unnamed Tributary to Wenze
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
Wenzel	10+25	**Gravel/cobble**	4	137.0	85.3	41

US 12 Unnamed Tributary to Wenzel Slough
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	Douglas-fir, Coast	Pseudotsuga menziesii var. menzi.	33.5	38.0
Tree Type #2:				
Tree Type #3:				
Tree Type #4:				
Tree Type #5:				
Tree Type #6:				
Tree Type #7:				
Tree Type #8:				
Tree Type #9:				
Tree Type #10:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

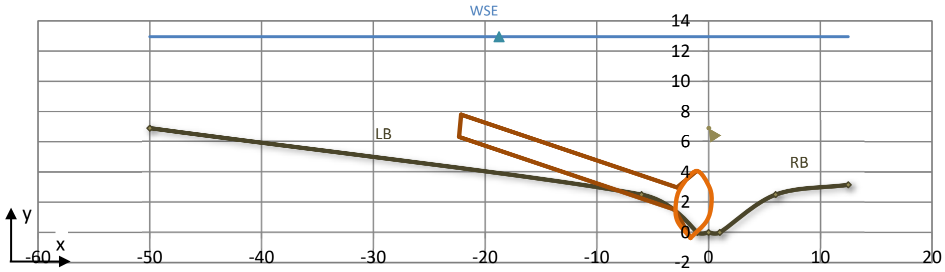
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

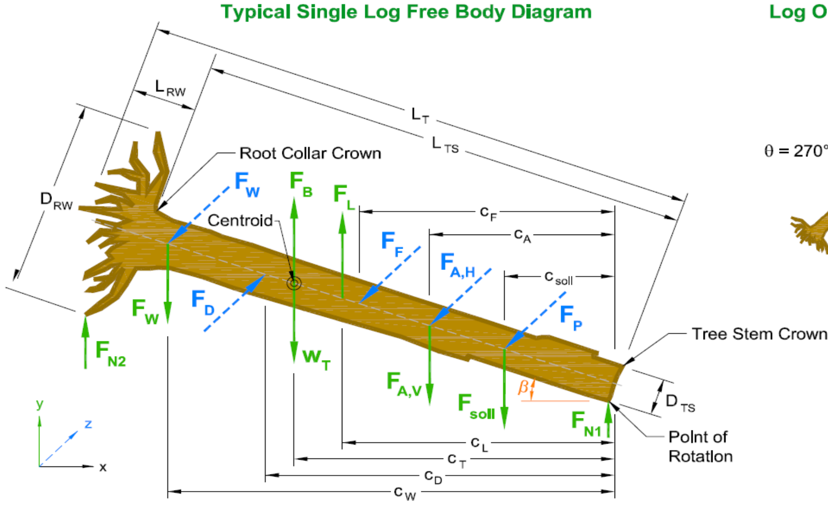


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

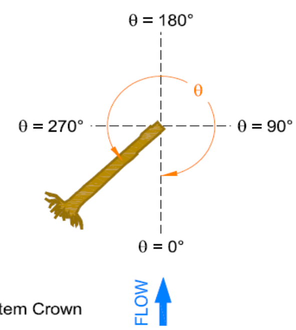
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	135.0	10.0	Root collar: Bottom	-3.00	1.50	-0.37	7.80	42.40

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	49.0	13.7	62.7	2,105	3,915
↓Thalweg	0.0	0.1	0.1	3	5
Total	49.0	13.8	62.8	2,108	3,920

Lift Force

C_{LT}	0.09
F_L (lbf)	12

Vertical Force Balance

F_B (lbf)	3,920	↑
F_L (lbf)	12	↑
W_T (lbf)	2,108	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,824	↑
FS_V	0.54	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.08	0.26	0.81	0.00	0.96	134

Horizontal Force Balance

F_D (lbf)	134	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	134	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	3.15	0.87	0
Total	-	0	5.15	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	21.0	15.0	17.2	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	51,325
M_r (lbf)	26,478
FS_M	0.52 ⊗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

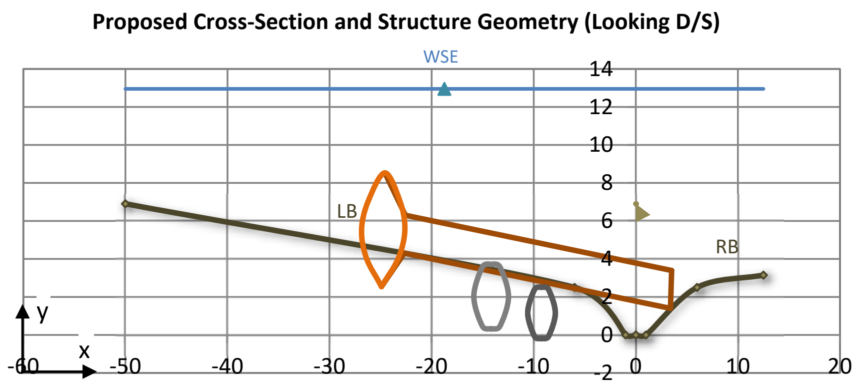
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

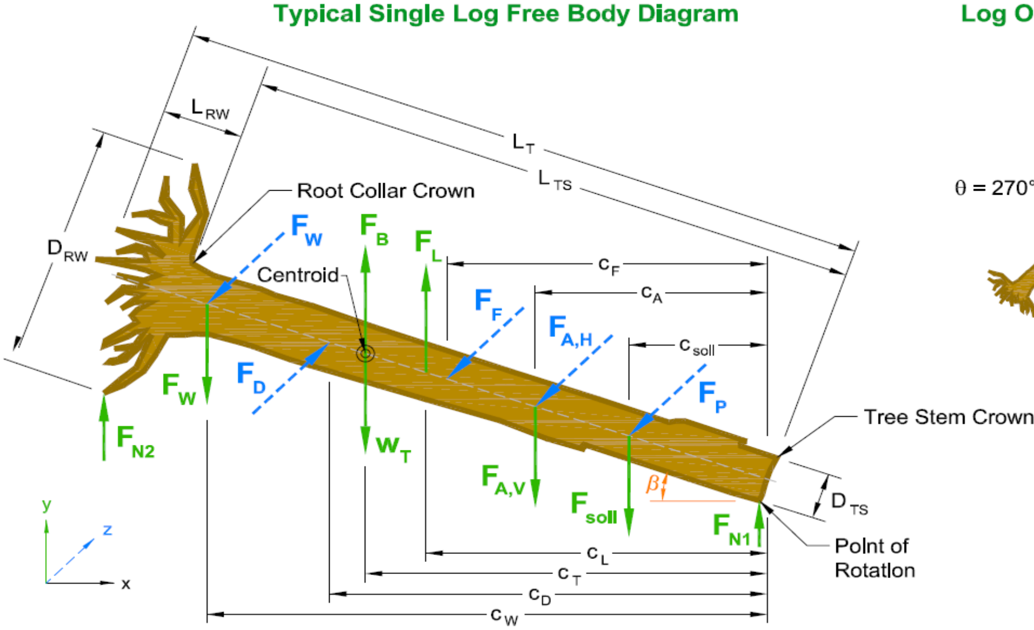


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

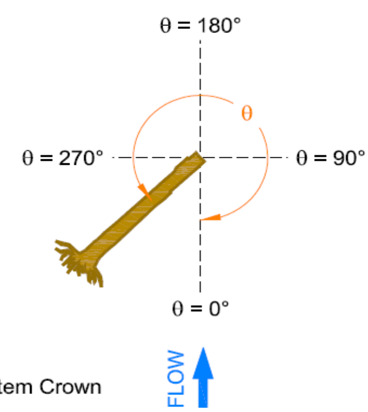
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	225.0	-4.5	Stem tip: Bottom	3.40	1.40	1.40	8.53	76.48

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	116.2	32.7	148.9	4,995	9,292
↓Thalweg	0.0	0.0	0.0	0	0
Total	116.2	32.7	148.9	4,995	9,292

Lift Force

C_{LT}	0.25
F_L (lbf)	63

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	63	↑
W_T (lbf)	4,995	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	4,230	↓
ΣF_V (lbf)	129	↑
FS_V	0.99	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.15	0.23	0.76	0.00	1.05	265

Horizontal Force Balance

F_D (lbf)	265	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	265	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	5.40	0.87	0
Total	-	0	7.40	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	24.9	20.0	23.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	163,794	
M_r (lbf)	162,725	
FS_M	0.99	⊗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	18.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	2.70	18.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	3.40	25.0	0.0	20.6	2,115	0	0	2,115	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

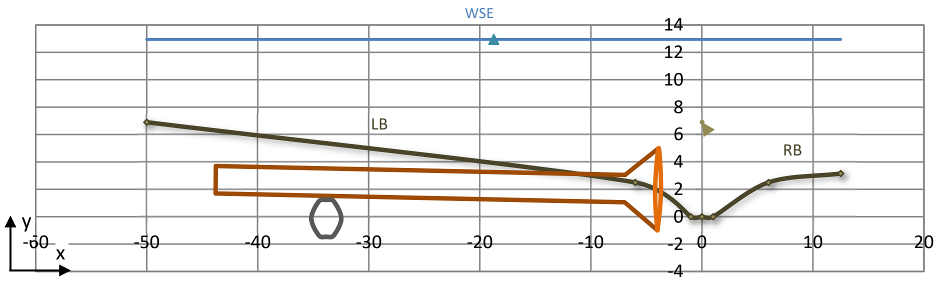
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

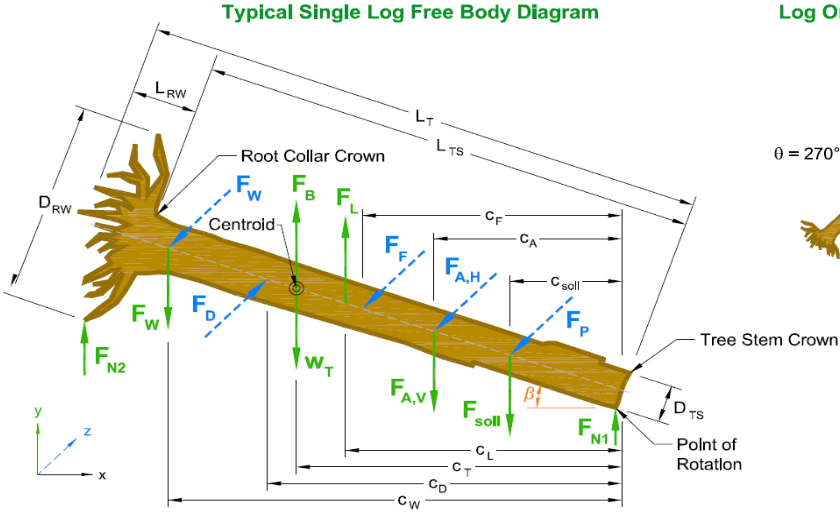


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

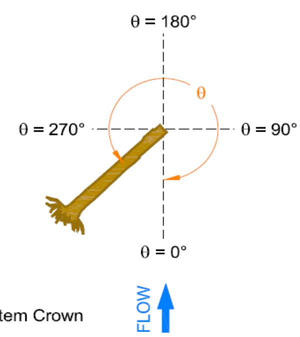
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	85.0	1.0	Rootwad: Bottom	-4.00	-1.00	-1.00	5.00	5.84

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	31.40	2.58	1.29

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	116.2	31.3	147.5	4,949	9,205
↓Thalweg	0.0	1.4	1.4	53	87
Total	116.2	32.7	148.9	5,002	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292
F_L (lbf)	0
W_T (lbf)	5,002
F_{soil} (lbf)	6,910
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	2,026
ΣF_V (lbf)	4,646
FS_V	1.50

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	81.0	81.0	6,910
Total	0.0	81.0	81.0	6,910

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.01	0.23	1.02	0.00	1.05	20

Horizontal Force Balance

F_D (lbf)	20
F_P (lbf)	16,636
F_F (lbf)	4,032
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	88
ΣF_H (lbf)	20,737
FS_H	1,035.00

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	186
Bank	4.81	16,636	40.00	0.87	3,846
Total	-	16,636	42.00	-	4,032

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	0.0	35.8	23.0	15.7	20.0	20.9

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	214,489
M_r (lbf)	766,416
FS_M	3.57

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	10.0	0.0	10.3	1,057	0	0	1,013	44
Deadman	2.70	10.0	0.0	10.3	1,057	0	0	1,013	44
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

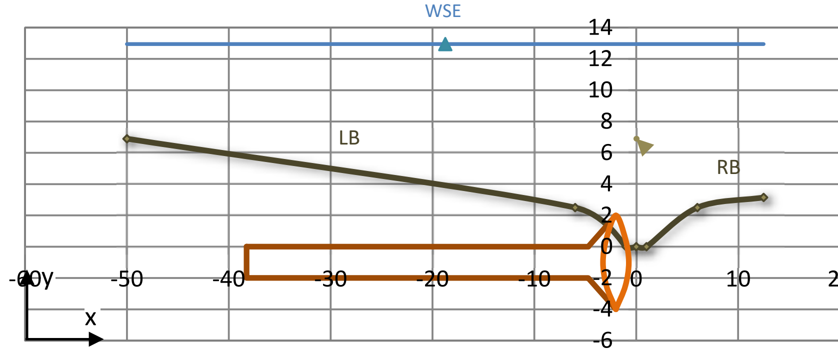
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Key Log	A Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

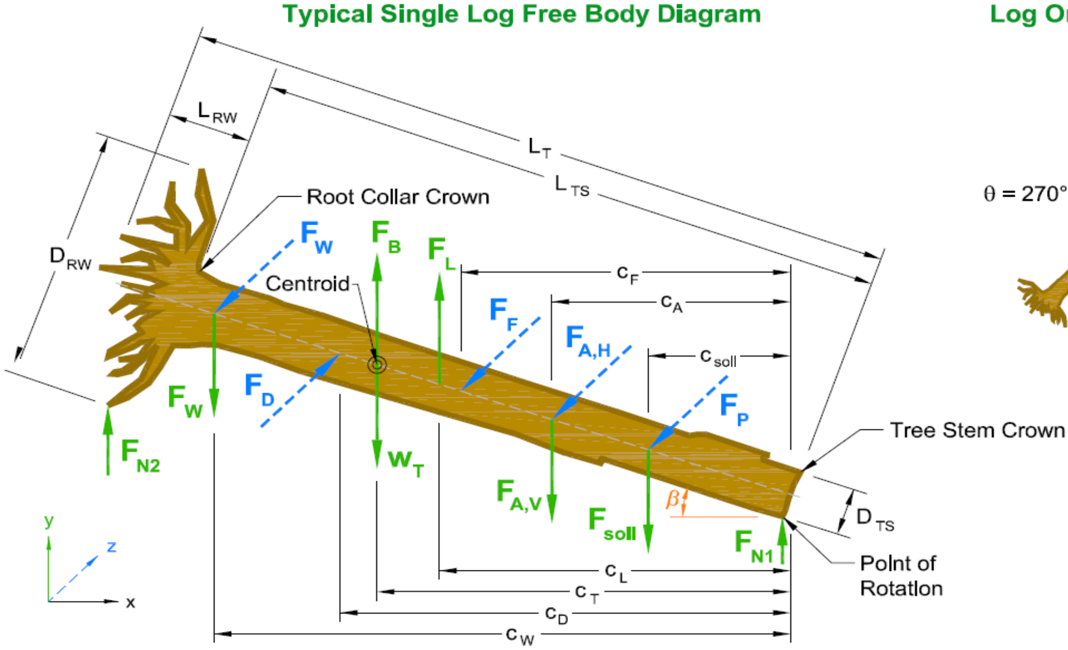


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

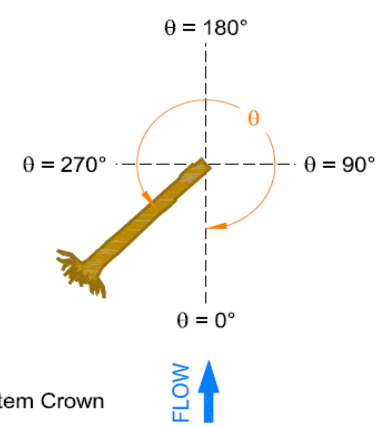
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	65.0	0.0	Rootwad: Bottom	-2.00	-4.00	-4.00	2.00	3.49

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	40.00	5.72	3.82

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	7.2	7.2	243	451
↓Thalweg	116.2	25.5	141.7	5,384	8,841
Total	116.2	32.7	148.9	5,626	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	0	
W_T (lbf)	5,626	↓
F_{soil} (lbf)	26,073	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	22,408	↓
FS_V	3.41	

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	305.7	305.7	26,073
Total	0.0	305.7	305.7	26,073

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.01	0.23	1.21	0.00	1.22	14

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	895
Bank	4.81	62,771	40.00	0.87	18,551
Total	-	62,771	42.00	-	19,447

Horizontal Force Balance

F_D (lbf)	14	→
F_P (lbf)	62,771	←
F_F (lbf)	19,447	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	82,204	←
FS_H	5,877.98	

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.9	0.0	0.0	22.9	20.0	20.0	20.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	159,470
M_r (lbf)	2,710,196
FS_M	17.00

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

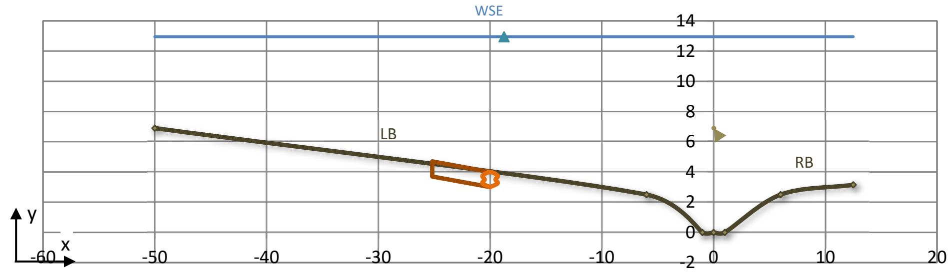
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

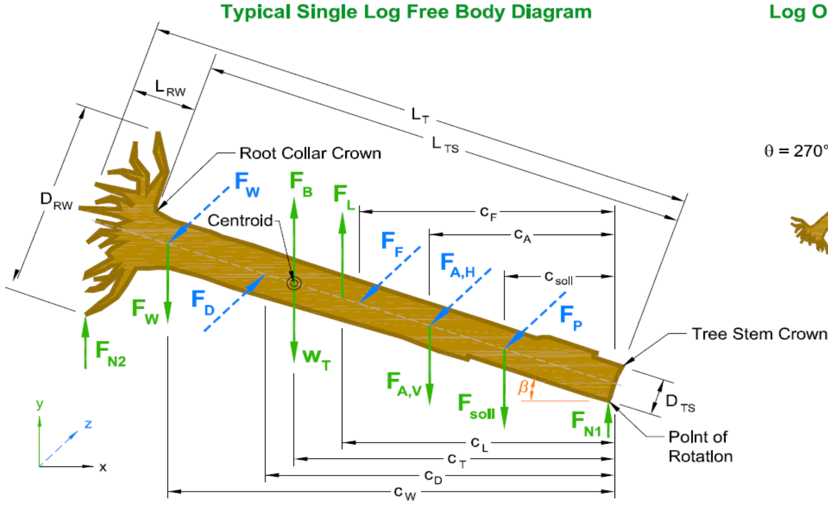


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

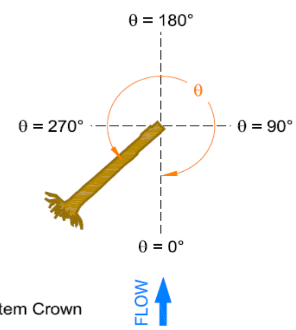
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	165.0	2.0	Root collar: Bottom	-20.00	3.00	3.00	4.70	0.97

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	20.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	980 ↑
F_L (lbf)	0
W_T (lbf)	527 ↓
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	453 ↑
FS_V	0.54

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.32	0.62	0.00	0.62	2

Horizontal Force Balance

F_D (lbf)	2 →
F_P (lbf)	0
F_F (lbf)	0
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	2 →
FS_H	0.00

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	20.00	0.87	0
Total	-	0	22.00	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	0.0	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,815
M_r (lbf)	5,266
FS_M	0.54

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

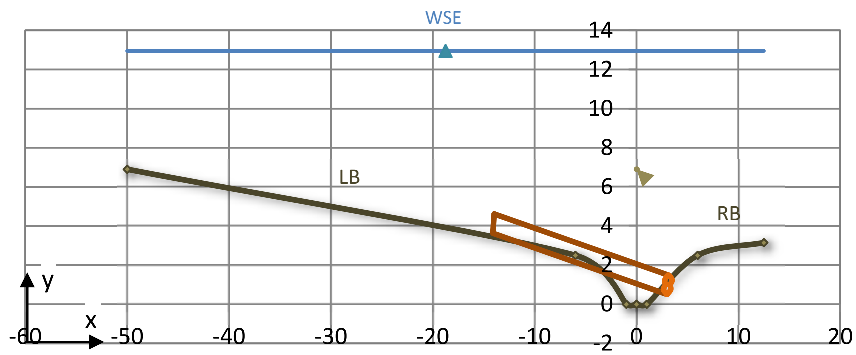
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	A Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

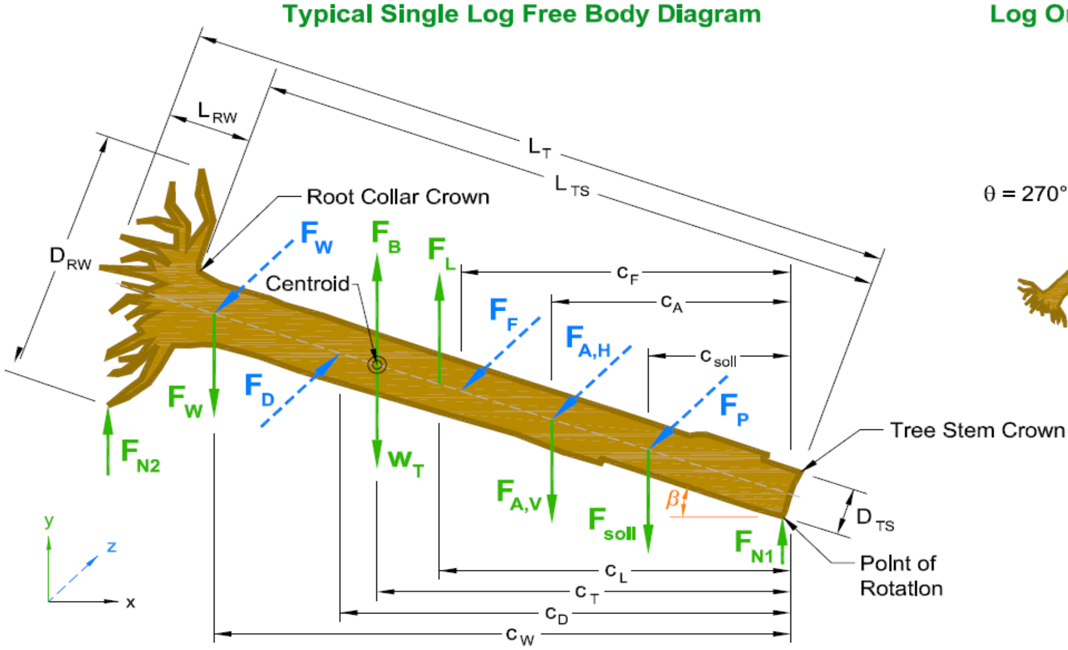


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

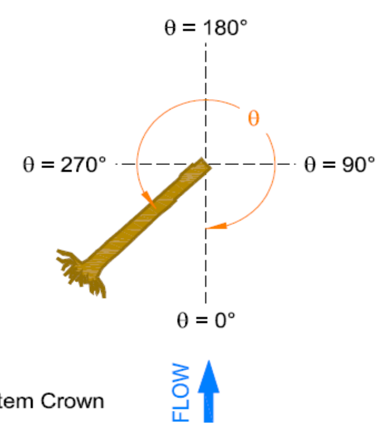
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	120.0	9.0	Root collar: Bottom	3.00	0.50	0.50	4.62	16.22

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.10
F_L (lbf)	5

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	5	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	459	↑
FS_V	0.53	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.03	0.32	1.02	0.00	1.08	58

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	6.85	0.87	0
Total	-	0	8.85	-	0

Horizontal Force Balance

F_D (lbf)	58	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	58	→
FS_H	0.00	⊗

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	6.5	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	10,322
M_r (lbf)	5,205
FS_M	0.50

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by Michael Rafferty, P.E.

Cluster A Total Forces

Vertical Force Balance

Σ F_V (lbf)	1,781	↓

Horizontal Force Balance

Σ F_H (lbf)	20,279	←

US 12 Unnamed Tributary to Wenzel Slough

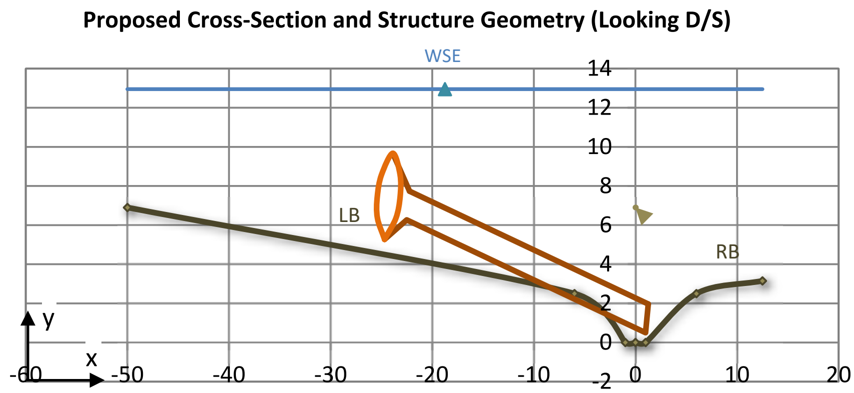
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

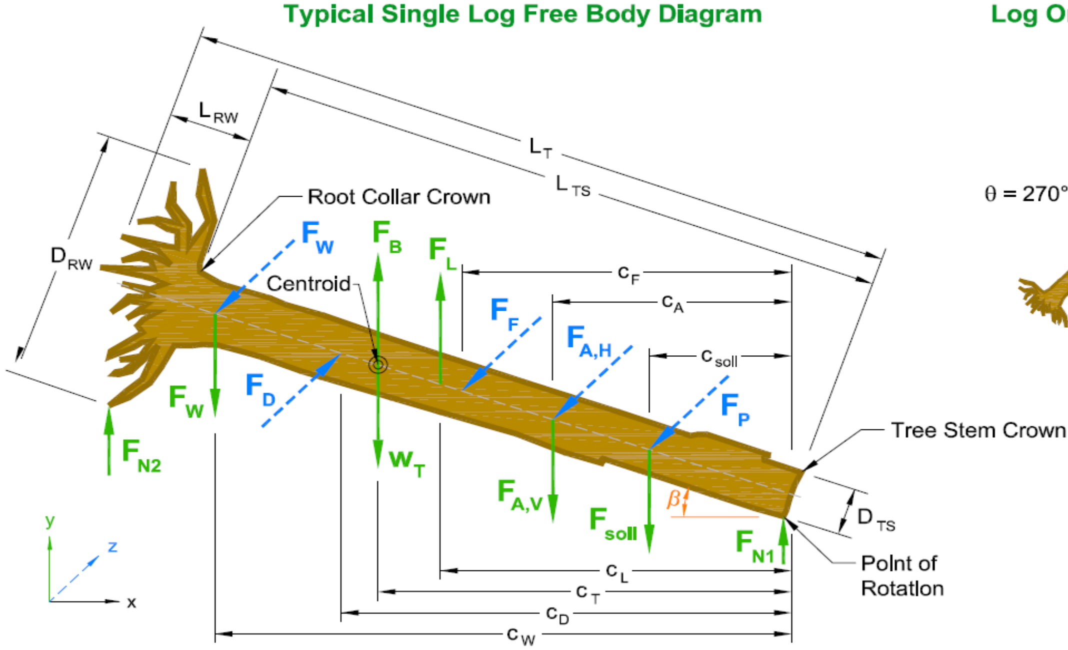


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

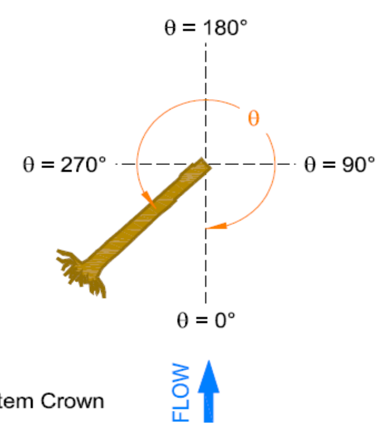
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	300.0	-12.0	Stem tip: Bottom	1.00	0.50	0.50	9.67	46.67

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	49.0	13.8	62.8	2,107	3,920
↓Thalweg	0.0	0.0	0.0	0	0
Total	49.0	13.8	62.8	2,107	3,920

Lift Force

C_{LT}	0.08
F_L (lbf)	12

Vertical Force Balance

F_B (lbf)	3,920
F_L (lbf)	12
W_T (lbf)	2,107
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,824
FS_V	0.54

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.09	0.26	1.02	0.00	1.23	188

Horizontal Force Balance

F_D (lbf)	188
F_P (lbf)	0
F_F (lbf)	0
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	188
FS_H	0.00

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	2.70	0.87	0
Total	-	0	4.70	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	9.4	15.0	17.2	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	51,918
M_r (lbf)	26,299
FS_M	0.51

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

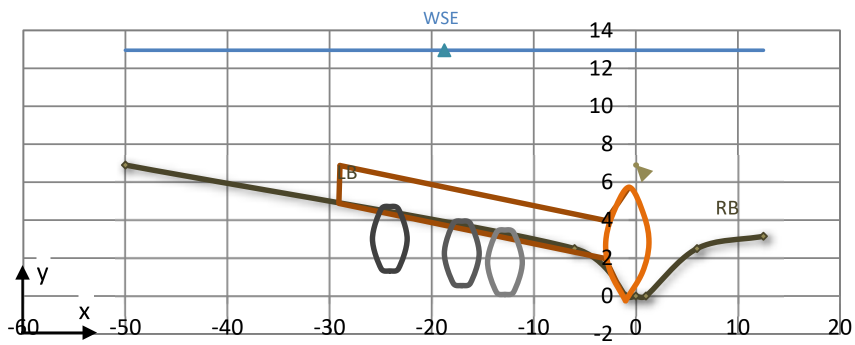
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

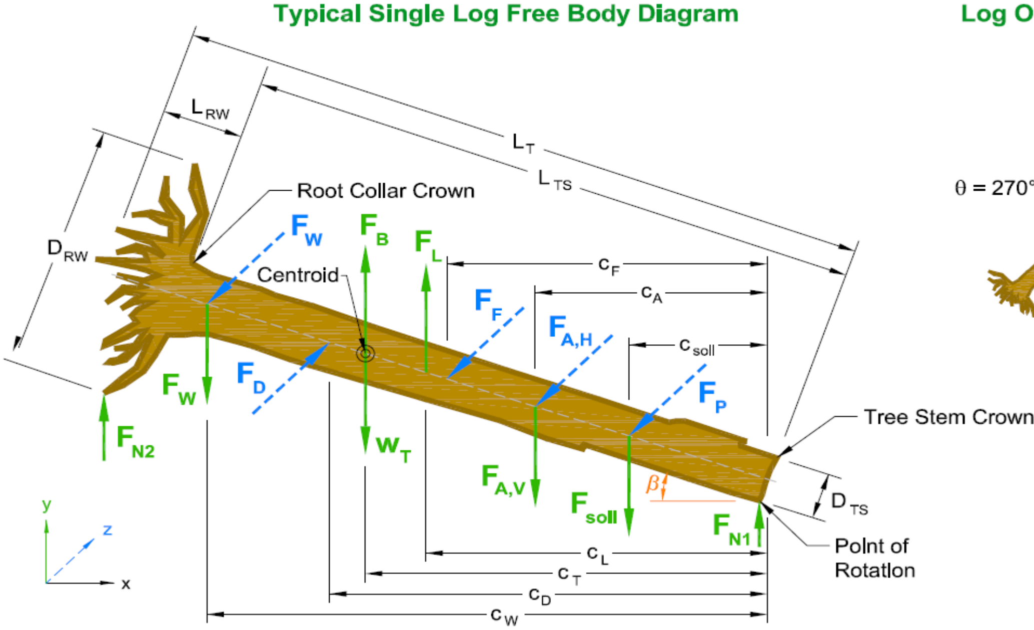


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

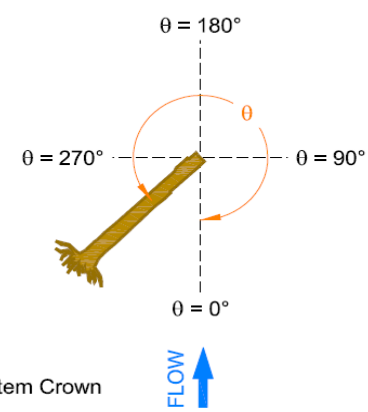
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	4.5	Rootwad: Bottom	-1.00	-0.25	-0.25	6.88	74.88

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	116.2	32.6	148.9	4,994	9,289
↓Thalweg	0.0	0.0	0.0	2	3
Total	116.2	32.7	148.9	4,996	9,292

Lift Force

C_{LT}	0.14
F_L (lbf)	33

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	33	↑
W_T (lbf)	4,996	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	6,346	↓
ΣF_V (lbf)	2,016	↓
FS_V	1.22	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.14	0.23	1.12	0.00	1.53	377

Horizontal Force Balance

F_D (lbf)	377	→
F_P (lbf)	0	
F_F (lbf)	1,747	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,371	←
FS_H	4.64	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	138
Bank	4.81	0	22.60	0.87	1,610
Total	-	0	24.60	-	1,747

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	12.8	20.0	23.0	0.0	22.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	165,988
M_r (lbf)	306,174
FS_M	1.84 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	3.40	7.0	0.0	20.6	2,115	0	0	2,115	0
Deadman	3.40	17.0	0.0	20.6	2,115	0	0	2,115	0
Deadman	3.40	23.0	0.0	20.6	2,115	0	0	2,115	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

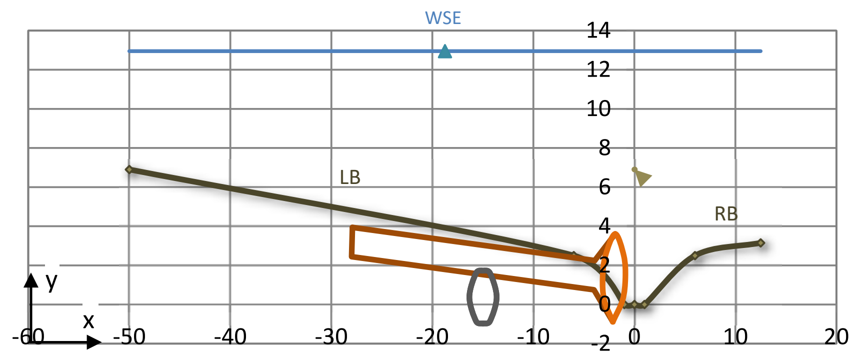
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

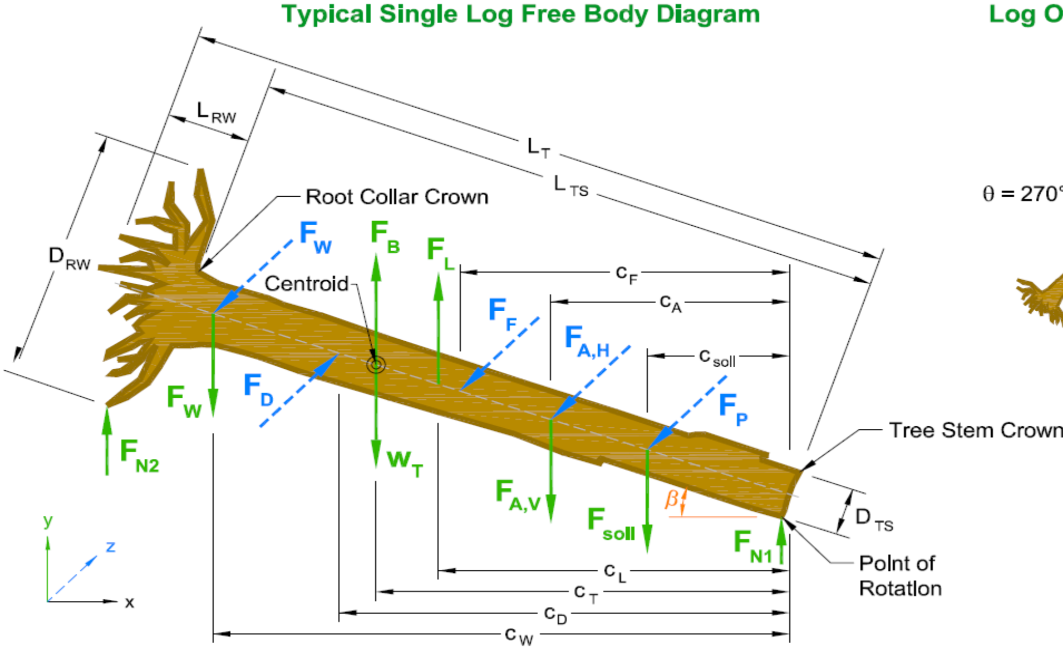


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

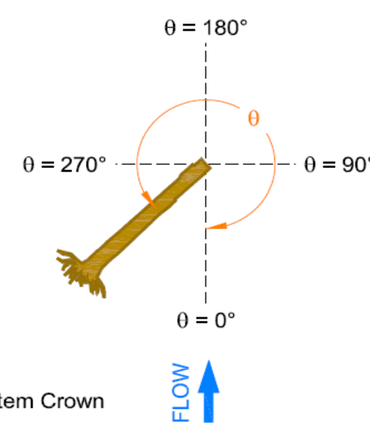
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	120.0	3.5	Root collar: Bottom	-4.00	0.75	-0.88	3.94	9.87

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	25.63	0.75	0.43

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	49.0	13.0	62.0	2,080	3,869
↓Thalweg	0.0	0.8	0.8	31	51
Total	49.0	13.8	62.8	2,111	3,920

Lift Force

C_{LT}	0.04
F_L (lbf)	1

Vertical Force Balance

F_B (lbf)	3,920	↑
F_L (lbf)	1	↑
W_T (lbf)	2,111	↓
F_{soil} (lbf)	1,389	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	2,115	↓
ΣF_V (lbf)	1,694	↓
FS_V	1.43	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	16.3	16.3	1,389
Total	0.0	16.3	16.3	1,389

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.26	0.94	0.00	0.97	31

Horizontal Force Balance

F_D (lbf)	31	→
F_P (lbf)	3,344	←
F_F (lbf)	1,469	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	4,782	←
FS_H	152.90	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	90
Bank	4.81	3,344	29.62	0.87	1,379
Total	-	3,344	31.62	-	1,469

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.3	29.9	27.8	17.3	12.8	14.8	17.0

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	68,460
M_r (lbf)	189,099
FS_M	2.76

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	15.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	2.70	15.0	0.0	10.3	1,057	0	0	1,057	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

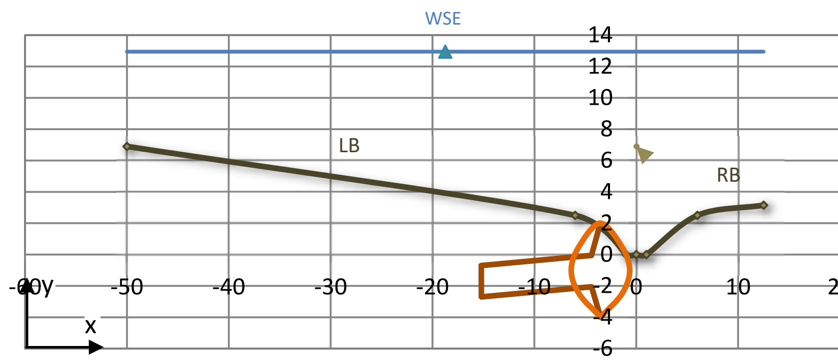
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Key Log	B Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

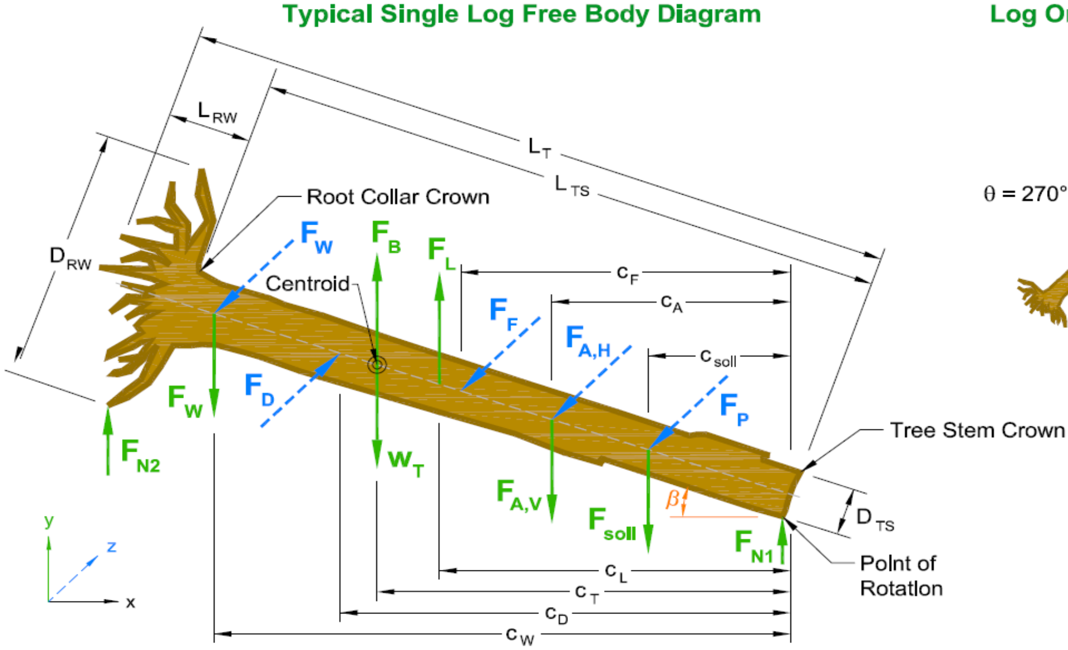


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

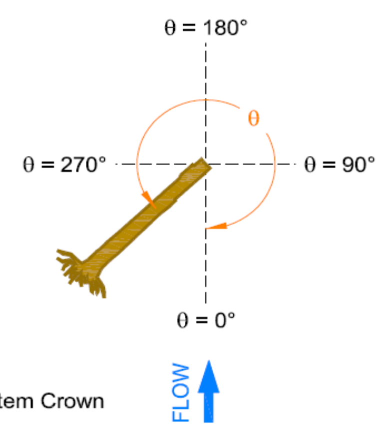
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	17.0	-1.0	Rootwad: Bottom	-3.50	-4.00	-4.00	2.00	7.89

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	40.00	4.12	3.08

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	0.0	7.1	7.1	237	440
↓Thalweg	116.2	25.6	141.9	5,390	8,852
Total	116.2	32.7	148.9	5,627	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	0	
W_T (lbf)	5,627	↓
F_{soil} (lbf)	21,026	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	17,362	↓
FS_V	2.87	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	246.5	246.5	21,026
Total	0.0	246.5	246.5	21,026

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.23	1.24	0.00	1.27	33

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	694
Bank	4.81	50,621	40.00	0.87	14,373
Total	-	50,621	42.00	-	15,067

Horizontal Force Balance

F_D (lbf)	33	→
F_P (lbf)	50,621	←
F_F (lbf)	15,067	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	65,655	←
FS_H	1,991.88	✓

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.9	0.0	0.0	22.9	20.0	20.0	20.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	160,187
M_r (lbf)	2,177,406
FS_M	13.59 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

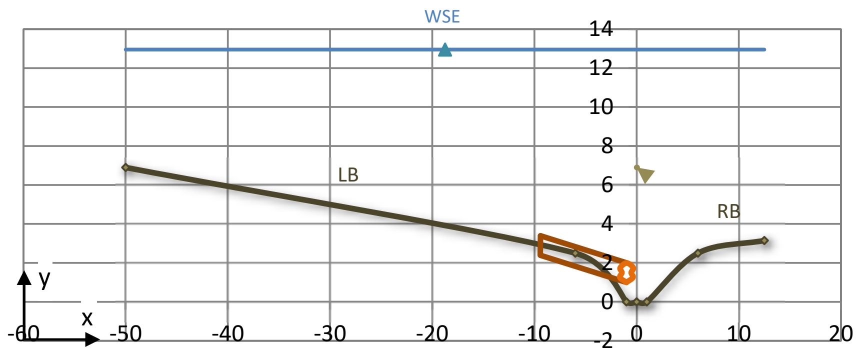
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

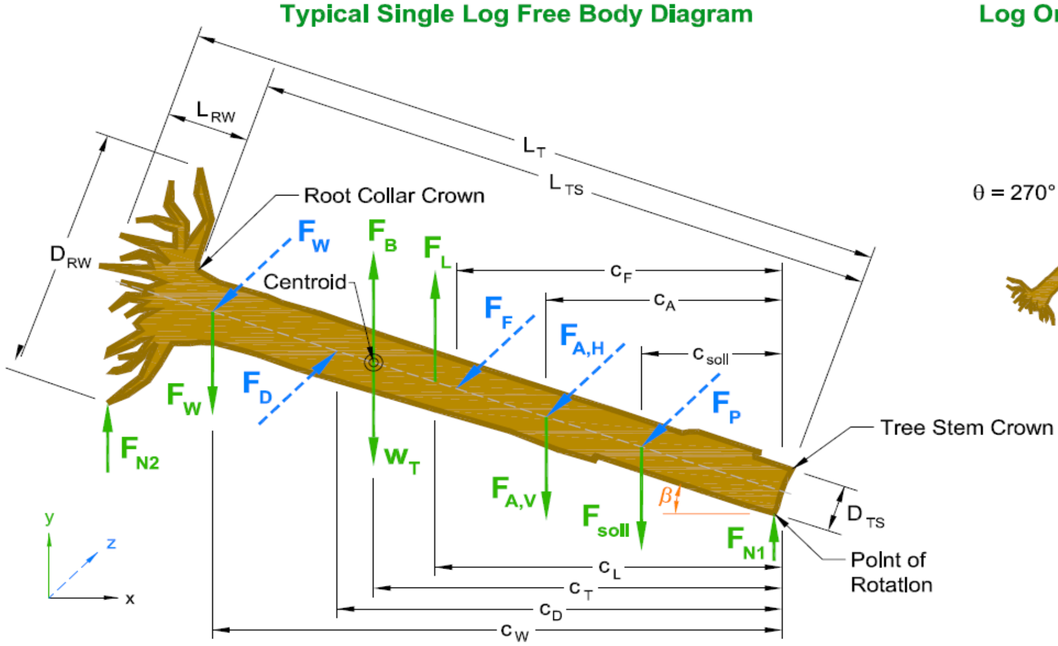


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

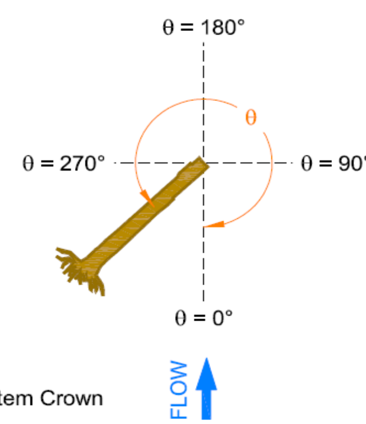
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	25.0	4.0	Root collar: Bottom	-1.00	1.00	1.00	3.39	5.88

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.04
F_L (lbf)	1

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	1	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	454	↑
FS_V	0.54	✕

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.01	0.32	0.54	0.00	0.55	11

Horizontal Force Balance

F_D (lbf)	11	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	11	→
FS_H	0.00	✕

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	12.85	0.87	0
Total	-	0	14.85	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	14.6	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	9,889
M_r (lbf)	5,257
FS_M	0.53

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

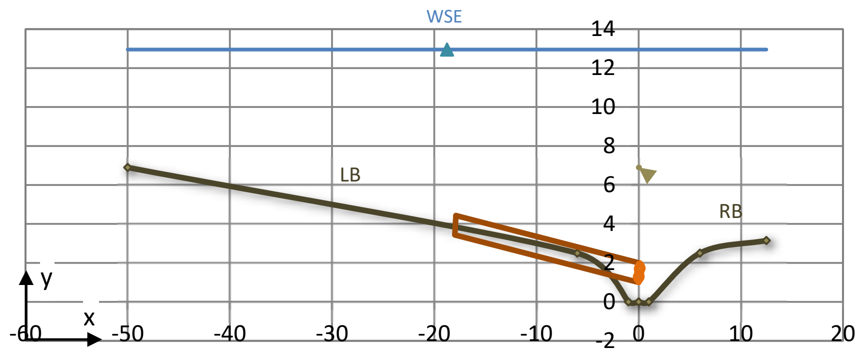
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	B Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

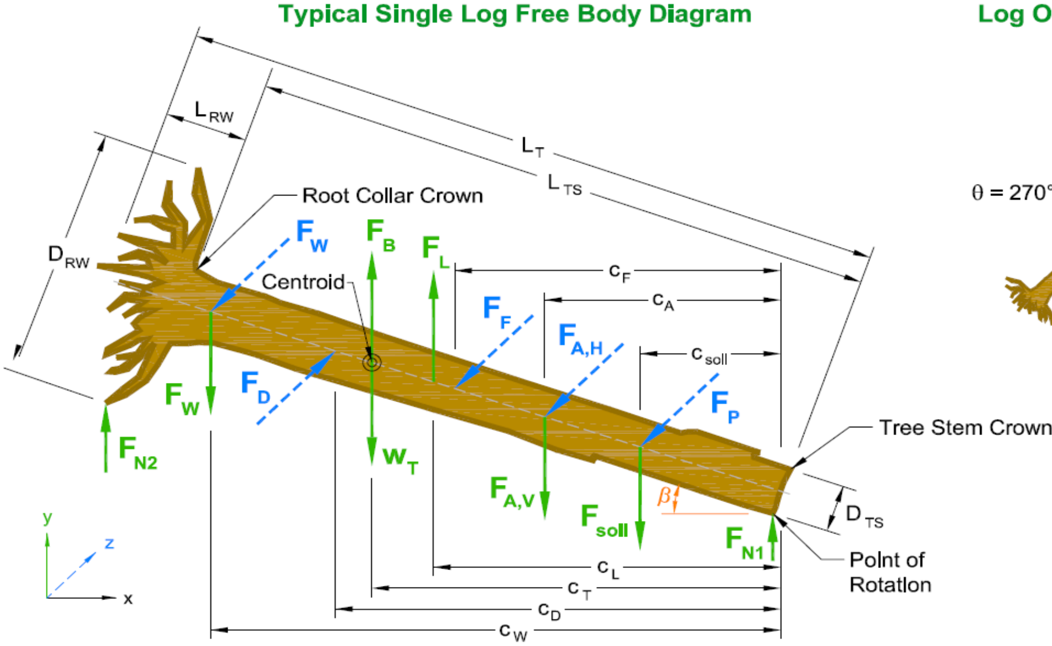


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

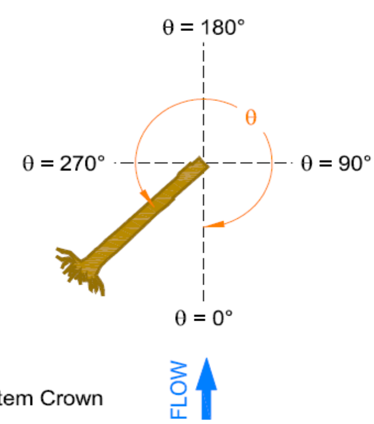
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	115.0	7.0	Root collar: Bottom	0.00	1.00	1.00	4.43	11.97

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.02
F_L (lbf)	1

Vertical Force Balance

F_B (lbf)	980
F_L (lbf)	1
W_T (lbf)	527
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	454
FS_V	0.54

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.32	1.08	0.00	1.13	44

Horizontal Force Balance

F_D (lbf)	44
F_P (lbf)	0
F_F (lbf)	0
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	44
FS_H	0.00

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	15.25	0.87	0
Total	-	0	17.25	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	16.0	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	10,172
M_r (lbf)	5,230
FS_M	0.51

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by Michael Rafferty, P.E.

Cluster B Total Forces

Vertical Force Balance

ΣF_V (lbf)	977	↓

Horizontal Force Balance

ΣF_H (lbf)	5,909	←

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

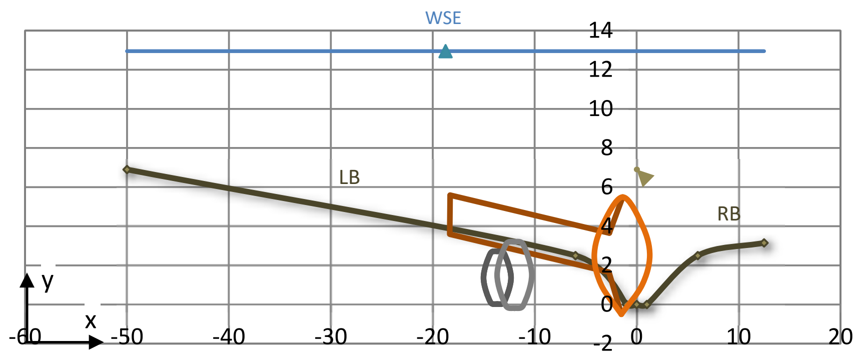
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Key Log	C Log #1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

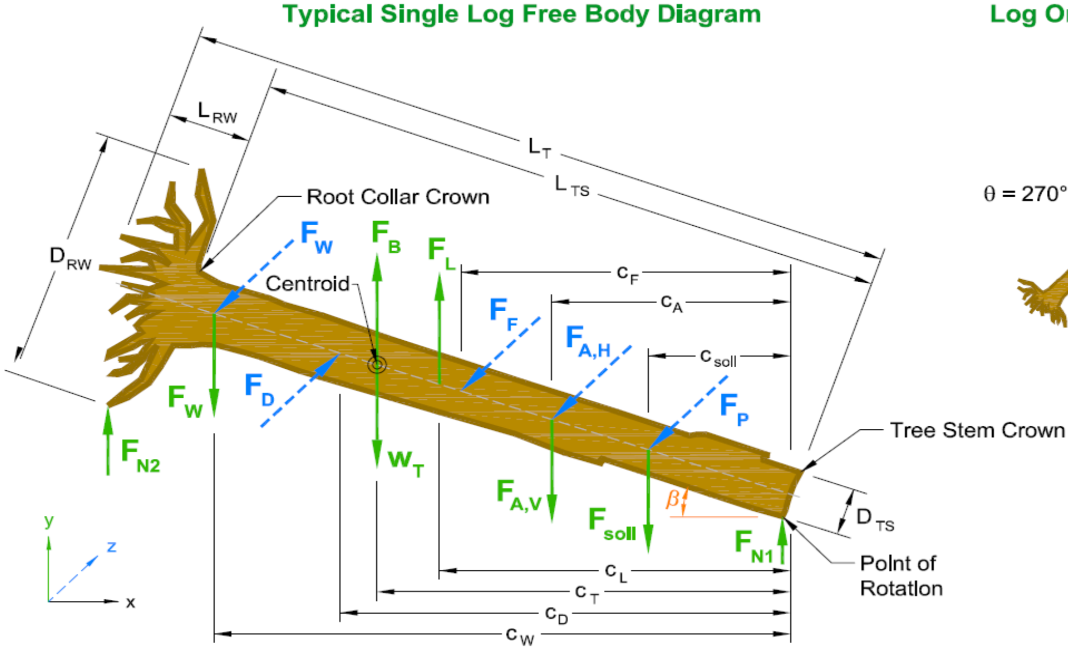


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

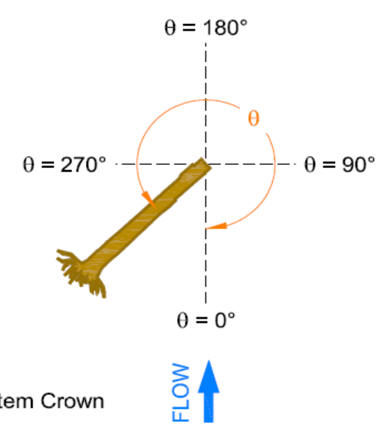
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	155.0	3.0	Rootwad: Bottom	-1.50	-0.50	-0.50	5.59	54.64

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	116.2	32.4	148.7	4,987	9,277
↓Thalweg	0.0	0.2	0.2	9	15
Total	116.2	32.7	148.9	4,997	9,292

Lift Force

C_{LT}	0.03
F_L (lbf)	6

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	6	↑
W_T (lbf)	4,997	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	4,230	↓
ΣF_V (lbf)	72	↑
FS_V	0.99	⊗

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.10	0.23	0.76	0.00	0.95	170

Horizontal Force Balance

F_D (lbf)	170	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	170	→
FS_H	0.00	⊗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	31.90	0.87	0
Total	-	0	33.90	-	0

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
23.0	35.0	20.0	23.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	161,234
M_r (lbf)	198,912
FS_M	1.23

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	11.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	2.70	11.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	3.40	15.0	0.0	20.6	2,115	0	0	2,115	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

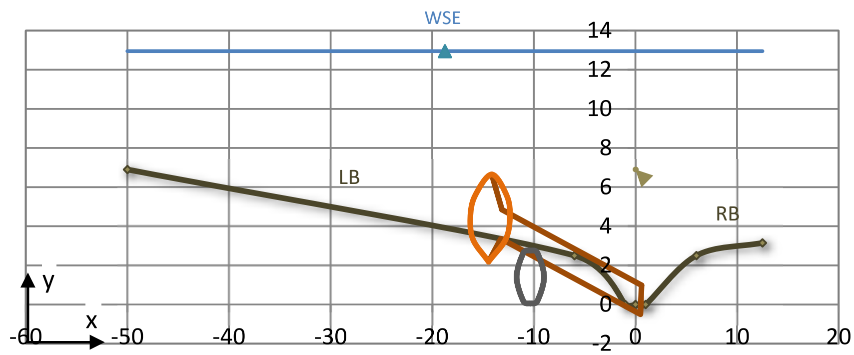
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

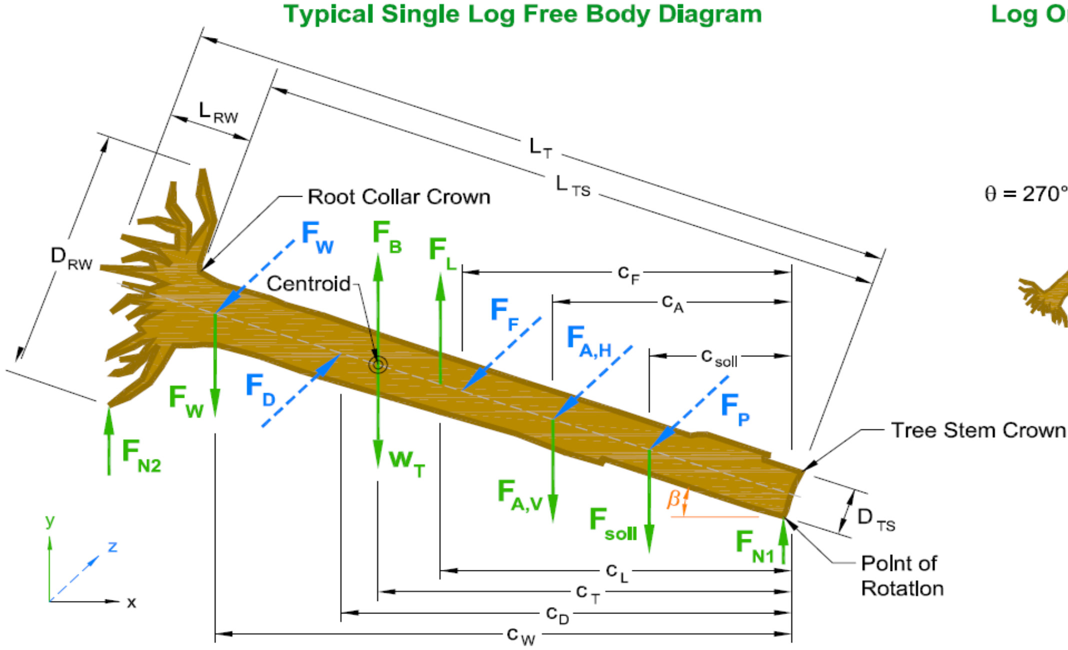


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

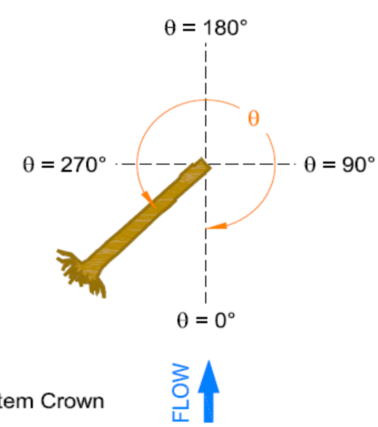
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	210.0	-8.0	Stem tip: Bottom	0.50	-0.50	-0.50	6.65	29.15

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	48.3	13.8	62.0	2,081	3,872
↓Thalweg	0.8	0.0	0.8	30	49
Total	49.0	13.8	62.8	2,111	3,920

Lift Force

C_{LT}	0.05
F_L (lbf)	4

Vertical Force Balance

F_B (lbf)	3,920 ↑
F_L (lbf)	4 ↑
W_T (lbf)	2,111 ↓
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	2,115 ↓
ΣF_V (lbf)	301 ↓
FS_V	1.08

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.06	0.26	0.56	0.00	0.63	61

Horizontal Force Balance

F_D (lbf)	61 →
F_P (lbf)	0
F_F (lbf)	260 ←
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	200 ←
FS_H	4.30

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	5.23	0.84	47
Bank	4.81	0	22.80	0.87	213
Total	-	0	28.03	-	260

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.2	28.1	15.0	17.2	0.0	13.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	50,455
M_r (lbf)	52,897
FS_M	1.05

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	22.0	0.0	10.3	1,057	0	0	1,057	0
Deadman	2.70	22.0	0.0	10.3	1,057	0	0	1,057	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

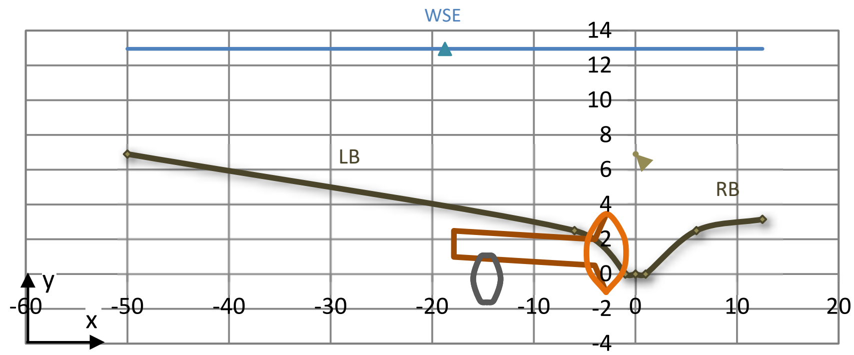
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

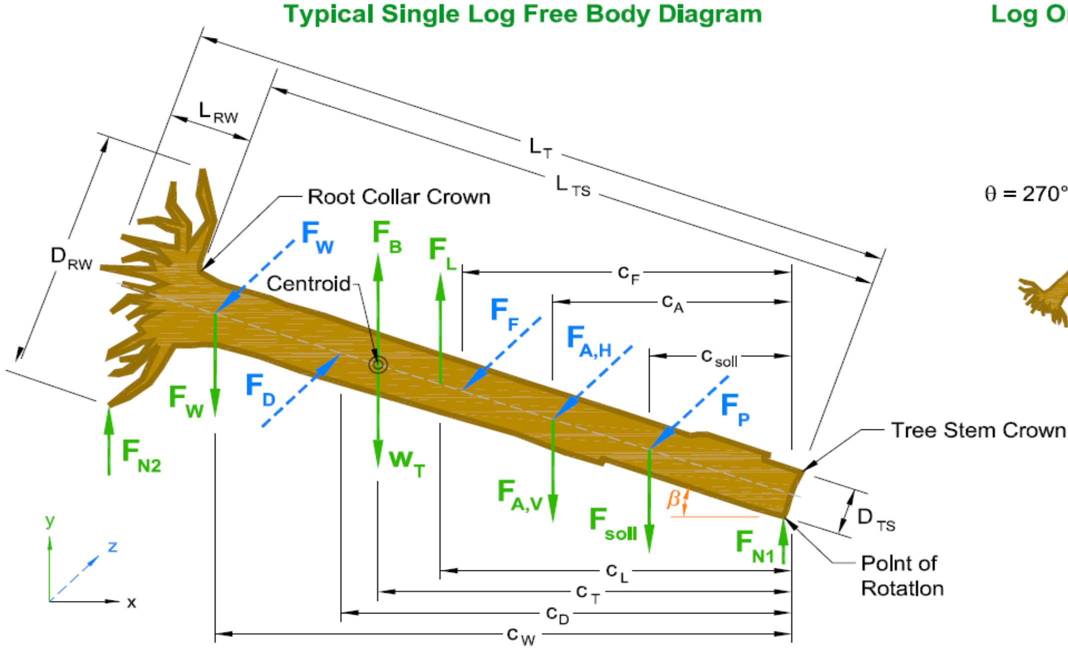


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	30.0	1.50	2.25	4.50	33.5	38.0

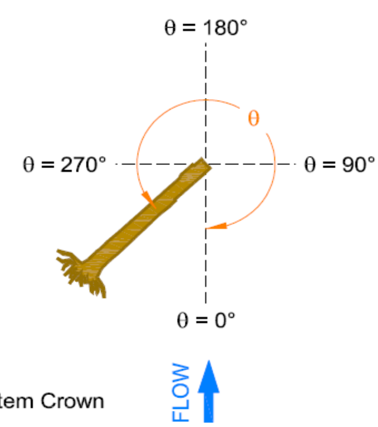
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	150.0	1.0	Root collar: Bottom	-4.00	0.50	-1.04	3.46	12.44

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	25.57	1.20	0.77

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	49.0	12.5	61.5	2,065	3,840
↓Thalweg	0.0	1.3	1.3	49	80
Total	49.0	13.8	62.8	2,113	3,920

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	3,920	↑
F_L (lbf)	0	
W_T (lbf)	2,113	↓
F_{soil} (lbf)	2,528	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	1,239	↓
ΣF_V (lbf)	1,960	↓
FS_V	1.50	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	29.6	29.6	2,528
Total	0.0	29.6	29.6	2,528

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.26	0.77	0.00	0.81	33

Horizontal Force Balance

F_D (lbf)	33	→
F_P (lbf)	6,085	←
F_F (lbf)	1,700	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	875	←
ΣF_H (lbf)	8,628	←
FS_H	263.00	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	103
Bank	4.81	6,085	30.00	0.87	1,597
Total	-	6,085	32.00	-	1,700

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
17.3	0.0	27.8	17.3	12.8	15.0	17.0

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	68,623
M_r (lbf)	240,791
FS_M	3.51 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.70	6.5	0.0	10.3	1,057	0	0	620	438
Deadman	2.70	6.5	0.0	10.3	1,057	0	0	620	438
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

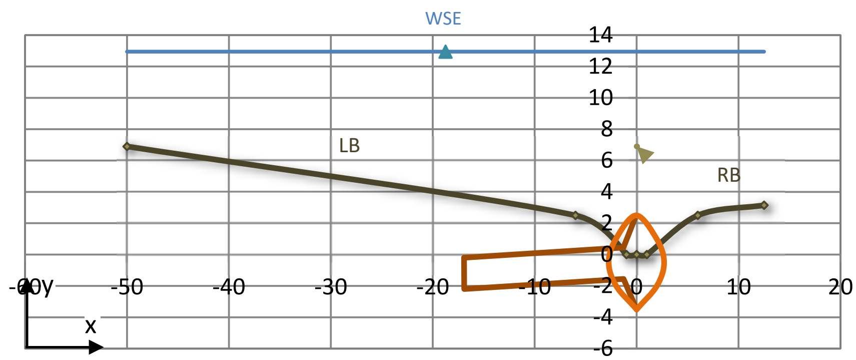
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Key Log	C Log #4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

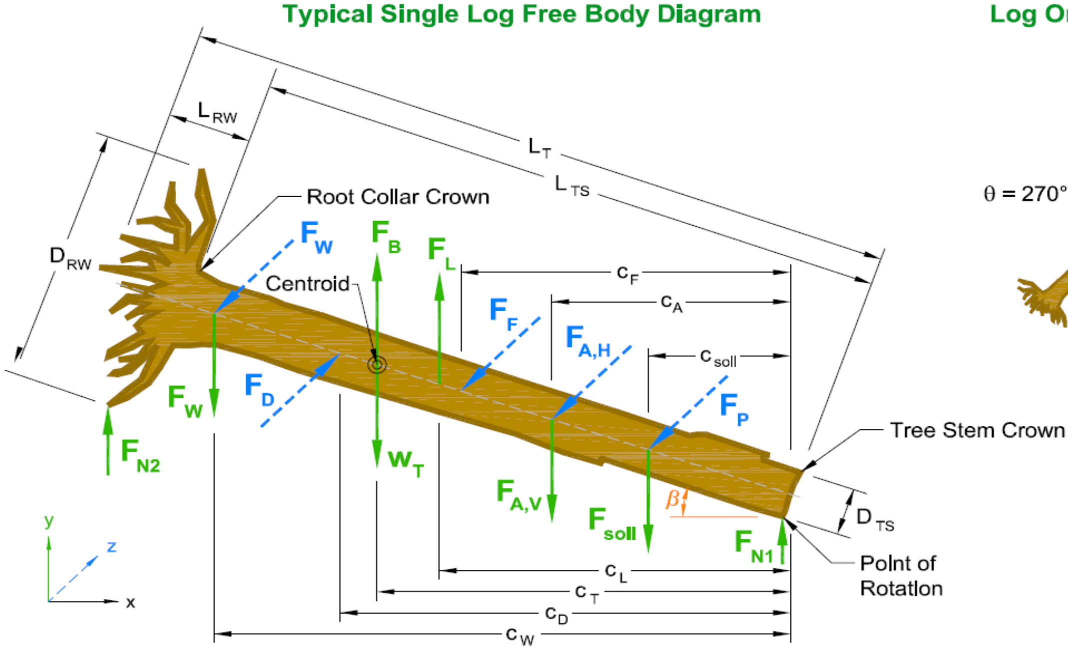


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	40.0	2.00	3.00	6.00	33.5	38.0

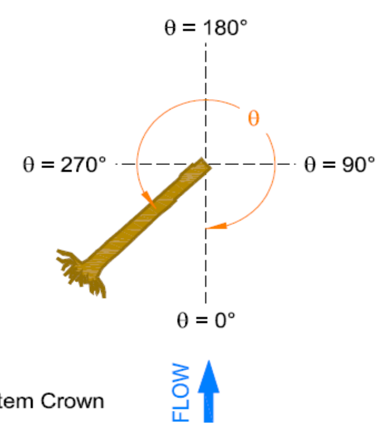
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	25.0	-1.0	Rootwad: Bottom	0.00	-3.50	-3.50	2.50	10.62

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	35.70	3.79	2.50

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	5.5	11.4	16.9	567	1,054
↓Thalweg	110.7	21.3	132.0	5,017	8,238
Total	116.2	32.7	148.9	5,583	9,292

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	9,292	↑
F_L (lbf)	0	
W_T (lbf)	5,583	↓
F_{soil} (lbf)	15,210	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	11,502	↓
FS_V	2.24	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	178.3	178.3	15,210
Total	0.0	178.3	178.3	15,210

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	0.23	1.24	0.00	1.28	45

Horizontal Force Balance

F_D (lbf)	45	→
F_P (lbf)	36,619	←
F_F (lbf)	9,963	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	46,537	←
FS_H	1,039.48	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	4.30	0.84	988
Bank	4.81	36,619	37.70	0.87	8,975
Total	-	36,619	42.00	-	9,963

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.9	0.0	37.9	22.9	17.8	20.0	23.7

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	214,119
M_r (lbf)	1,696,517
FS_M	7.92 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

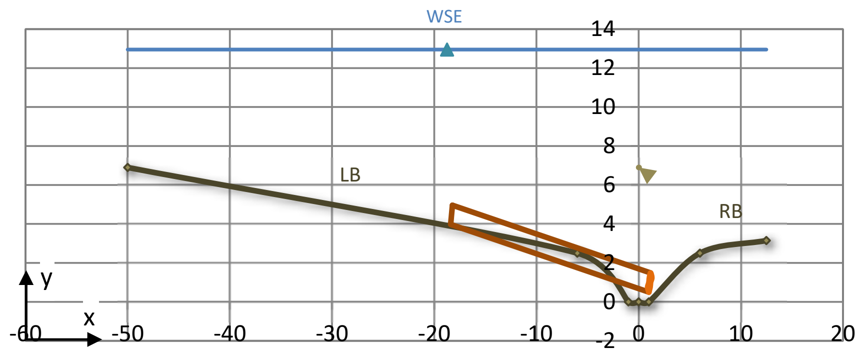
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

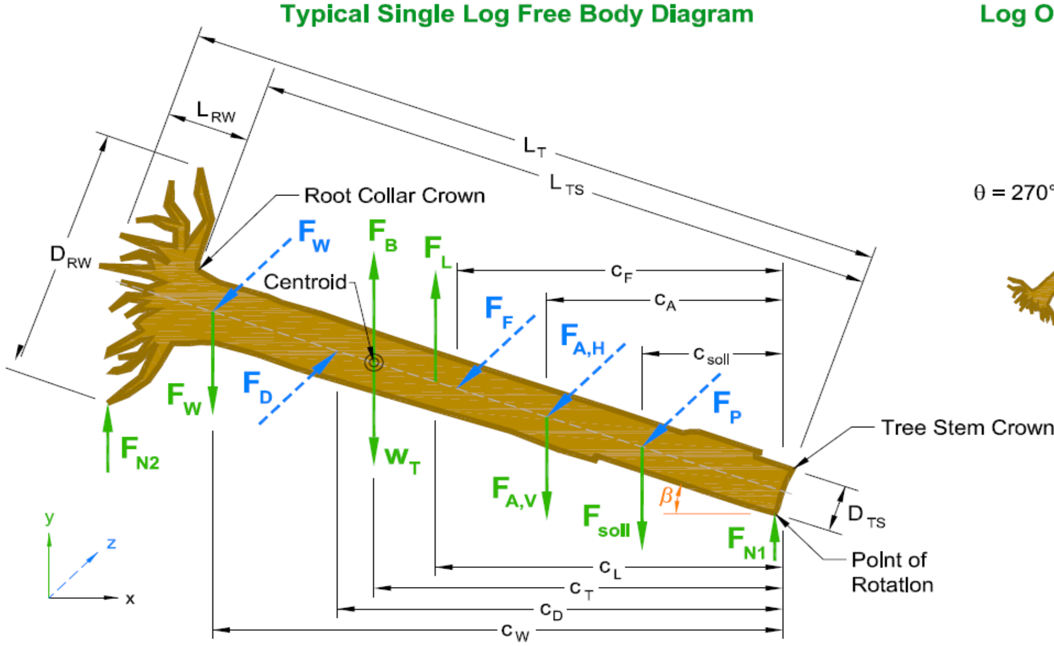


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

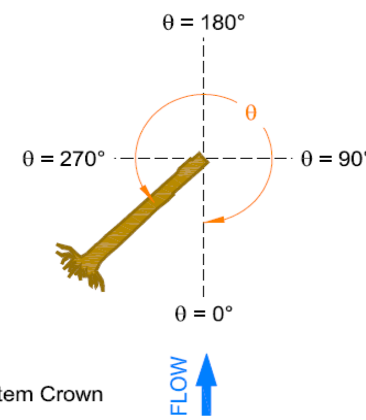
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	100.0	10.0	Root collar: Bottom	1.00	0.50	0.50	4.96	15.59

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.07
F_L (lbf)	4

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Vertical Force Balance

F_B (lbf)	980
F_L (lbf)	4
W_T (lbf)	527
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	457
FS_V	0.54

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.03	0.32	1.10	0.00	1.17	60

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	µ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	11.70	0.87	0
Total	-	0	13.70	-	0

Horizontal Force Balance

F_D (lbf)	60
F_P (lbf)	0
F_F (lbf)	0
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	60
FS_H	0.00

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	6.8	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	10,289
M_r (lbf)	5,189
FS_M	0.50

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by
Michael Rafferty, P.E.

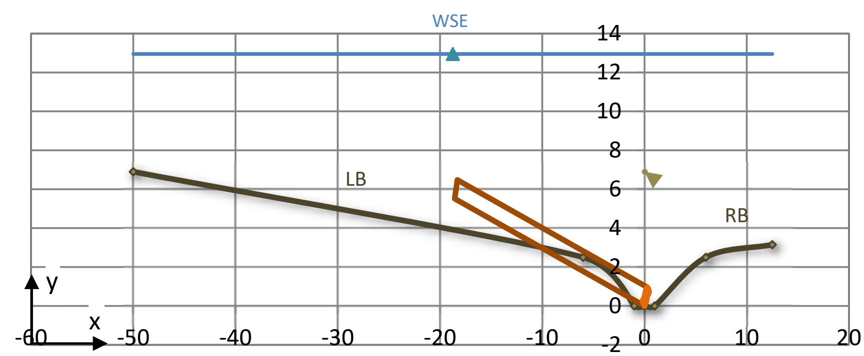
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Wenzel	Rootwad	Left bank	Straight	10+25	12.95	1.62	1.84

Multi-Log Structures	Layer	Log ID
	Stacked	C Log #6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-50.00	6.90
Top LB	-6.00	2.50
Toe LB	-1.00	0.00
Thalweg	0.00	0.00
Toe RB	1.00	0.00
Top RB	6.00	2.50
Fldpln RB	12.50	3.15

Proposed Cross-Section and Structure Geometry (Looking D/S)

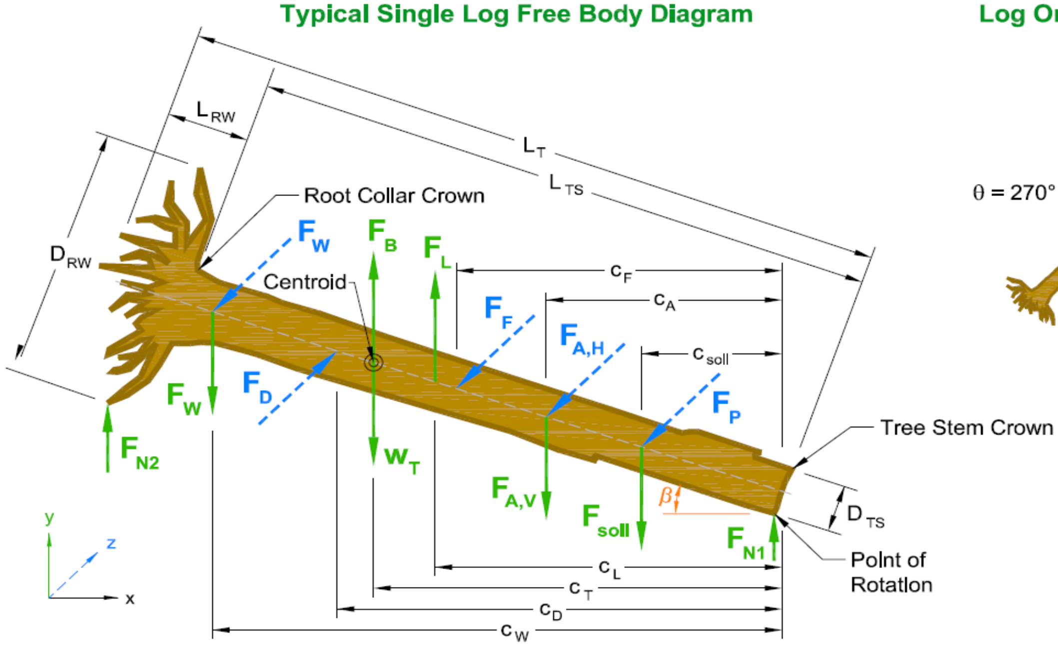


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	20.0	1.00	-	-	33.5	38.0

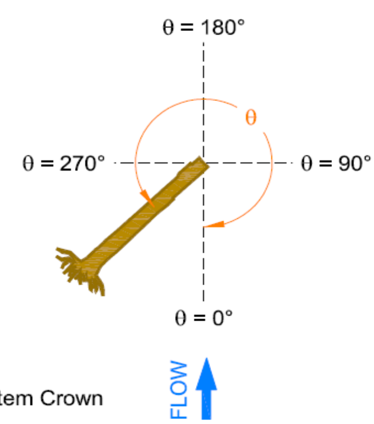
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	105.0	16.0	Root collar: Bottom	0.00	0.00	0.00	6.47	17.19

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	129.0	80.3	40.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	15.7	0.0	15.7	527	980
↓Thalweg	0.0	0.0	0.0	0	0
Total	15.7	0.0	15.7	527	980

Lift Force

C_{LT}	0.08
F_L (lbf)	4

Vertical Force Balance

F_B (lbf)	980	↑
F_L (lbf)	4	↑
W_T (lbf)	527	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	458	↑
FS_V	0.54	⊗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.03	0.32	1.13	0.00	1.20	68

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	0
Bank	4.81	0	6.90	0.87	0
Total	-	0	8.90	-	0

Horizontal Force Balance

F_D (lbf)	68	→
F_P (lbf)	0	
F_F (lbf)	0	
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	68	→
FS_H	0.00	⊗

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
10.0	13.9	10.0	10.0	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	10,101
M_r (lbf)	5,065
FS_M	0.50

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

US 12 Unnamed Tributary to Wenzel Slough

Spreadsheet developed by Michael Rafferty, P.E.

Cluster C Total Forces

Vertical Force Balance

ΣF_V (lbf)	1,275	↓

Horizontal Force Balance

ΣF_H (lbf)	8,530	←

US 12 Unnamed Tributary to Wenzel Slough
Notation, Units, and List of Symbols

Notation

Symbol	Description	Unit
A_W	Wetted area of channel at design discharge	ft^2
A_{Tp}	Projected area of wood in plane perpendicular to flow	ft^2
c_D	Centroid of the drag force along log axis	ft
c_{Am}	Centroid of a mechanical anchor along log axis	ft
c_{Ar}	Centroid of a ballast boulder along log axis	ft
c_{Asoil}	Centroid of the added ballast soil along log axis	ft
$c_{F\&N}$	Centroid of friction and normal forces along log axis	ft
c_L	Centroid of the lift force along log axis	ft
c_P	Centroid of the passive soil force along log axis	ft
c_{soil}	Centroid of the vertical soil forces along log axis	ft
$c_{T,B}$	Centroid of the buoyancy force along log axis	ft
$c_{T,W}$	Centroid of the log volume along log axis	ft
c_{WI}	Centroid of a wood interaction force along log axis	ft
C_{Lrock}	Coefficient of lift for submerged boulder	-
C_{LT}	Effective coefficient of lift for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_D*	Effective coefficient of drag for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_W	Wave drag coefficient of submerged tree	-
$d_{b,avg}$	Average buried depth of log	ft
$d_{b,max}$	Maximum buried depth of log	ft
d_w	Maximum flow depth at design discharge in reach	ft
D_{50}	Median grain size in millimeters (SI units)	mm
D_r	Equivalent diameter of boulder	ft
D_{RW}	Assumed diameter of rootwad	ft
D_{TS}	Nominal diameter of tree stem (DBH)	ft
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-
e	Void ratio of soils	-
$F_{A,H}$	Total horizontal load capacity of anchor techniques	lbf
$F_{A,HP}$	Passive soil pressure applied to log from soil ballast	lbf
$F_{A,Hr}$	Horizontal resisting force on log from boulder	lbf
F_{Am}	Load capacity of mechanical anchor	lbf
$F_{A,V}$	Total vertical load capacity of anchor techniques	lbf
$F_{A,Vr}$	Vertical resisting force on log from boulder	lbf
$F_{A,Vsoil}$	Vertical soil loading on log from added ballast soil	lbf
F_B	Buoyant force applied to log	lbf
F_D	Drag forces applied to log	lbf
$F_{D,r}$	Drag forces applied to boulder	lbf
F_F	Friction force applied to log	lbf
F_H	Resultant horizontal force applied to log	lbf
F_L	Lift force applied to log	lbf
$F_{L,r}$	Lift force applied to boulder	lbf
F_P	Passive soil pressure force applied to log	lbf
F_{soil}	Vertical soil loading on log	lbf
$F_{W,H}$	Horizontal forces from interactions with other logs	lbf
$F_{W,V}$	Vertical forces from interactions with other logs	lbf

Notation (continued)

Symbol	Description	Unit
F_V	Resultant vertical force applied to log	lbf
Fr_L	Log Froude number	-
FS_V	Factor of Safety for Vertical Force Balance	-
FS_H	Factor of Safety for Horizontal Force Balance	-
FS_M	Factor of Safety for Moment Force Balance	-
g	Gravitational acceleration constant	ft/s^2
K_P	Coefficient of Passive Earth Pressure	-
$L_{T,em}$	Total embedded length of log	ft
L_{RW}	Assumed length of rootwad	ft
L_T	Total length of tree (including rootwad)	ft
L_{Tf}	Length of log in contact with bed or banks	ft
L_{TS}	Length of tree stem (not including rootwad)	ft
$L_{TS,ex}$	Exposed length of tree stem	ft
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-
M_d	Driving moment about embedded tip	lbf
M_r	Driving moment about embedded tip	lbf
N	Blow count of standard penetration test	-
p_o	Porosity of soil volume	-
Q_{des}	Design discharge	cfs
R	Radius	ft
R_c	Radius of curvature at channel centerline	ft
SG_r	Specific gravity of quartz particles	-
SG_T	Specific gravity of tree	-
u_{avg}	Average velocity of cross section in reach	ft/s
u_{des}	Design velocity	ft/s
u_m	Adjusted velocity at outer meander bend	ft/s
V_{dry}	Volume of soils above stage level of design flow	ft^3
V_{sat}	Volume of soils below stage level of design flow	ft^3
V_{soil}	Total volume of soils over log	ft^3
V_{RW}	Volume of rootwad	ft^3
V_S	Volume of solids in soil (void ratio calculation)	ft^3
V_T	Total volume of log	ft^3
V_{TS}	Total volume of tree	ft^3
V_V	Volume of voids in soil	ft^3
V_{Adry}	Volume of ballast above stage of design flow	ft^3
V_{Awet}	Volume of ballast below stage of design flow	ft^3
$V_{r,dry}$	Volume of boulder above stage of design flow	ft^3
$V_{r,wet}$	Volume of boulder below stage of design flow	ft^3
W_{BF}	Bankfull width at structure site	ft
W_r	Effective weight of boulder	lbf
W_T	Total log weight	lbf
x	Horizontal coordinate (distance)	ft
y	Vertical coordinate (elevation)	ft
$y_{T,max}$	Minimum elevation of log	ft
$y_{T,min}$	Maximum elevation of log	ft

Greek Symbols

Symbol	Description	Unit
β	Tilt angle from stem tip to vertical	deg
γ_{bank}	Dry specific weight of bank soils	lb/ft^3
$\gamma_{bank,sat}$	Saturated unit weight of bank soils	lb/ft^3
γ'_{bank}	Effective buoyant unit weight of bank soils	lb/ft^3
γ_{bed}	Dry specific weight of stream bed substrate	lb/ft^3
γ'_{bed}	Effective buoyant unit weight of stream bed substrate	lb/ft^3
γ_{rock}	Dry unit weight of boulders	lb/ft^3
γ_s	Dry specific weight of soil	lb/ft^3
γ'_s	Effective buoyant unit weight of soil	lb/ft^3
γ_{Td}	Air-dried unit weight of tree (12% MC basis)	lb/ft^3
γ_{Tgr}	Green unit weight of tree	lb/ft^3
γ_w	Specific weight of water at 50ºF	lb/ft^3
η	Rootwad porosity	-
θ	Rootwad (or large end of log) orientation to flow	deg
μ	Coefficient of friction	-
ν	Kinematic viscosity of water at 50ºF	ft/s^2
Σ	Sum of forces	-
ϕ_{bank}	Internal friction angle of bank soils	deg
ϕ_{bed}	Internal friction angle of stream bed substrate	deg

Units

Notation	Description
cfs	Cubic feet per second
ft	Feet
lb	Pound
lbf	Pounds force
kg	Kilograms
m	Meters
mm	Millimeters
s	Seconds
yr	Year

Abbreviations

Notation	Description
ARI	Average return interval
Avg	Average
DBH	Diameter at breast height
deg	Degrees
Dia	Diameter
Dist	Distance
D/S	Downstream
ELJ	Engineered log jam
Ex	Example
Fldpln	Floodplain
H&H	Hydrologic and hydraulic
ID	Identification
i.e.	That is
LB	Left bank
LW	Large wood
Max	Maximum
MC	Moisture content
Min	Minimum
ML	Multi-log
SL	Single log
N/A	Not applicable
no	Number
Pt	Point
rad	Radians
RB	Right bank
RW	Rootwad
SL	Single log
Thw	Thalweg (lowest elevation in channel bed)
Typ	Typical
U.S.	United States
WS	Water surface
WSE	Water surface elevation
↑	Above
↓	Below

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name: 933616

Stream Name:

Drainage Area: 233 ac

Projected mean percent change in bankfull flow:

2040s: 12.8%

2080s: 16.5%

Projected mean percent change in bankfull width:

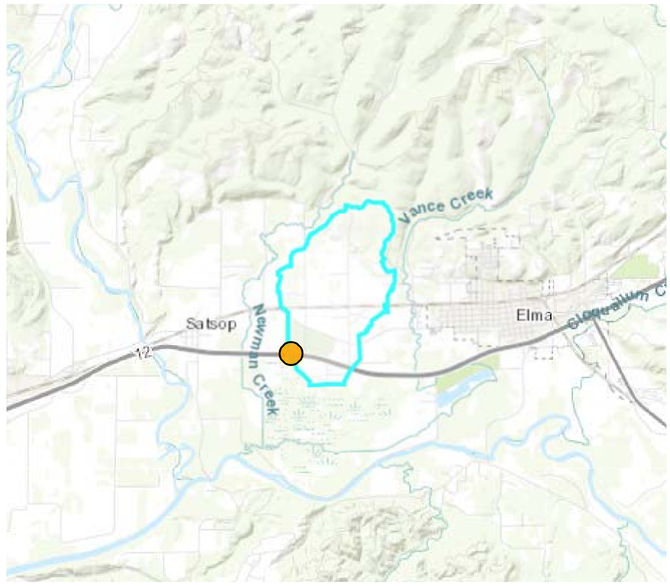
2040s: 6.2%

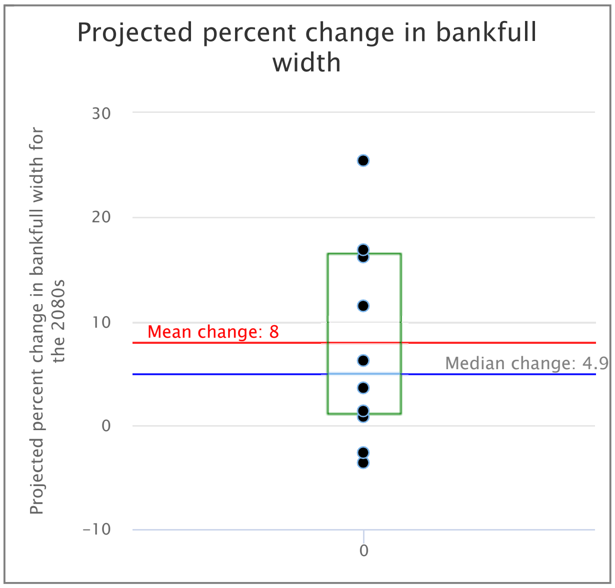
2080s: 8%

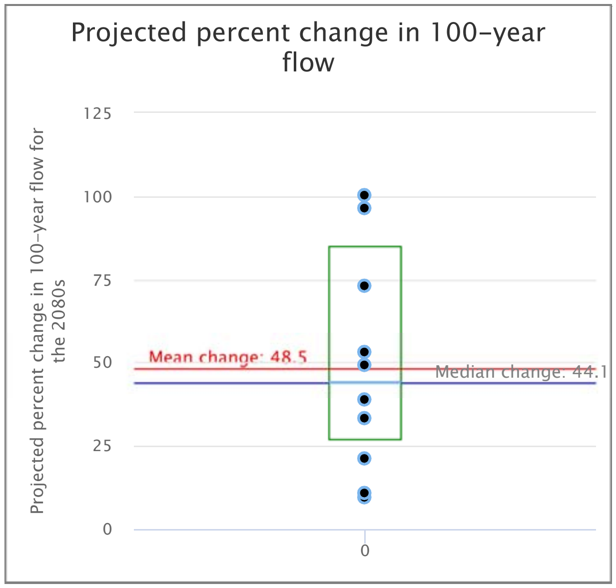
Projected mean percent change in 100-year flood:

2040s: 31.7%

2080s: 48.5%







Black dots are projections from 10 separate models

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Appendix H: SRH-2D Model Results

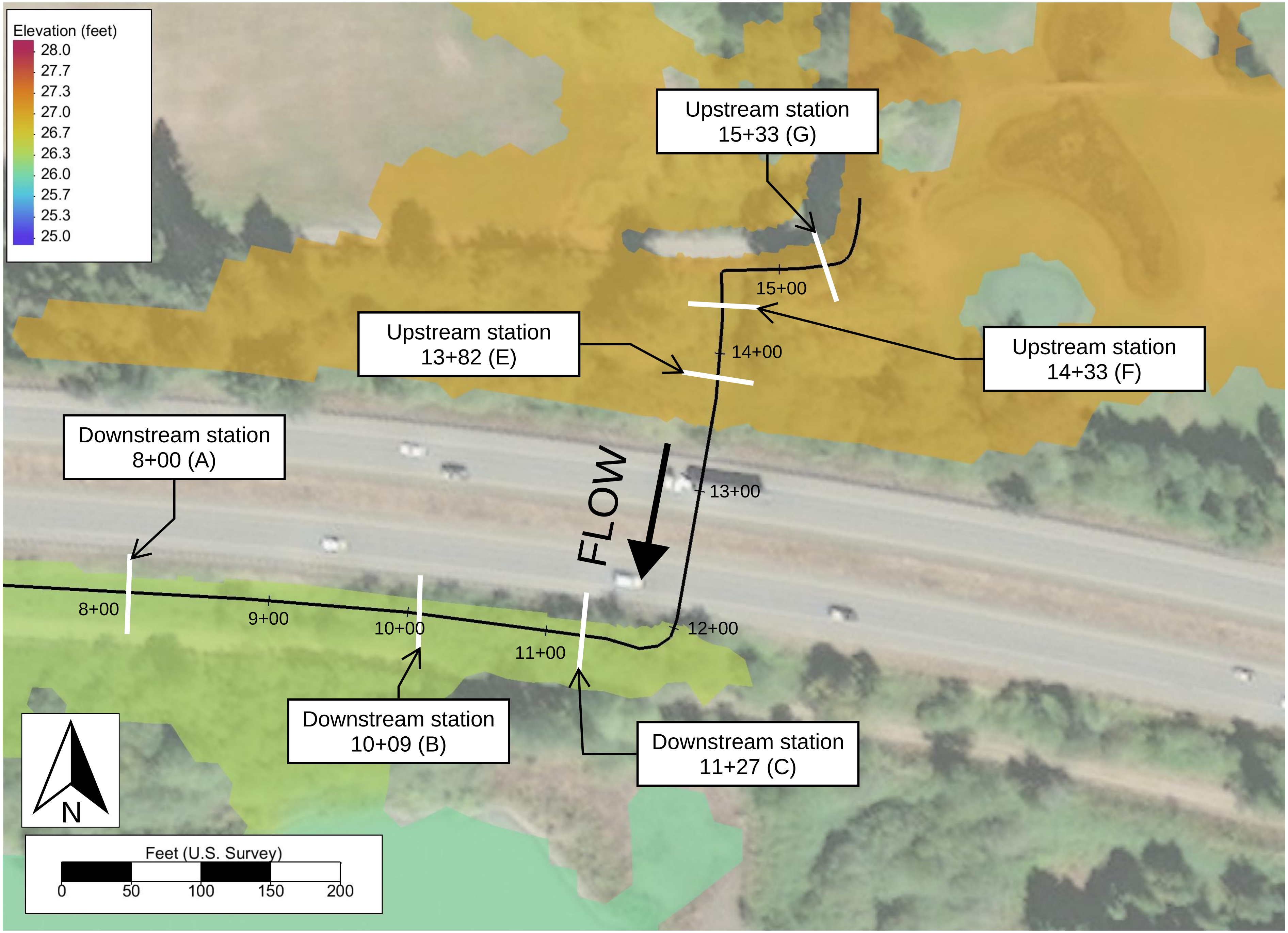

Figure H.1: Existing conditions 2-year water surface elevation

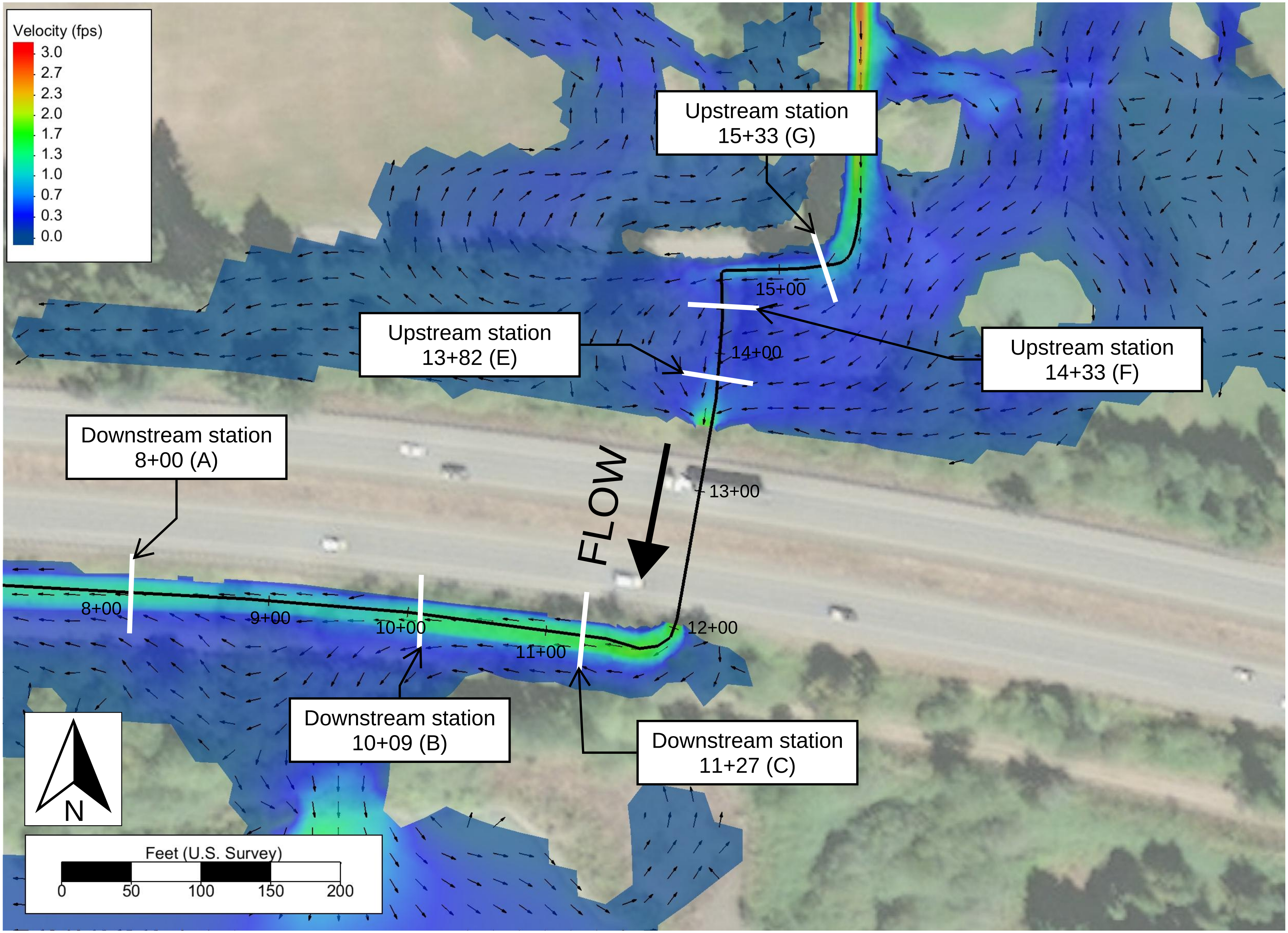

Figure H.2: Existing conditions 2-year velocity

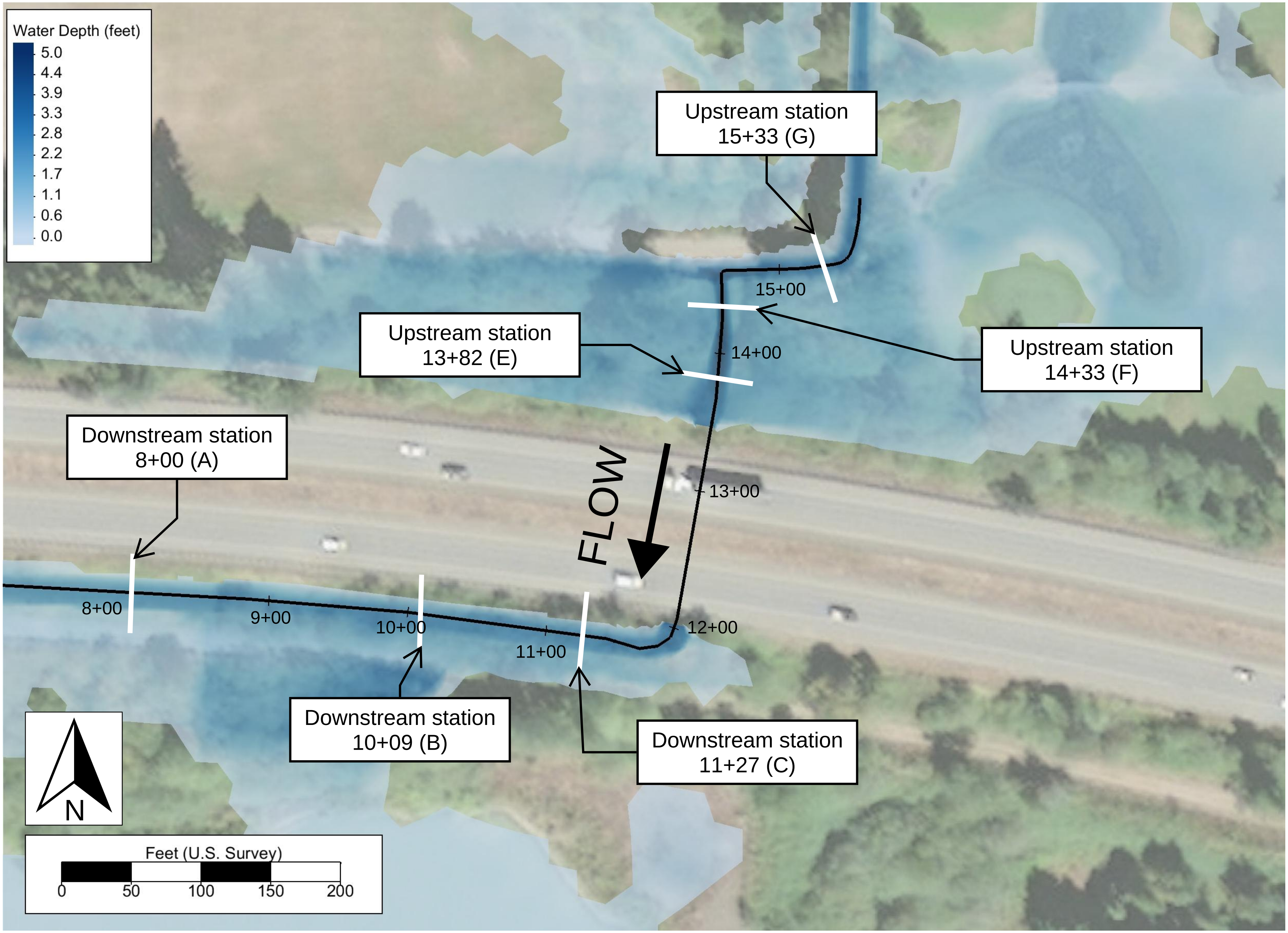

Figure H.3: Existing conditions 2-year water depth

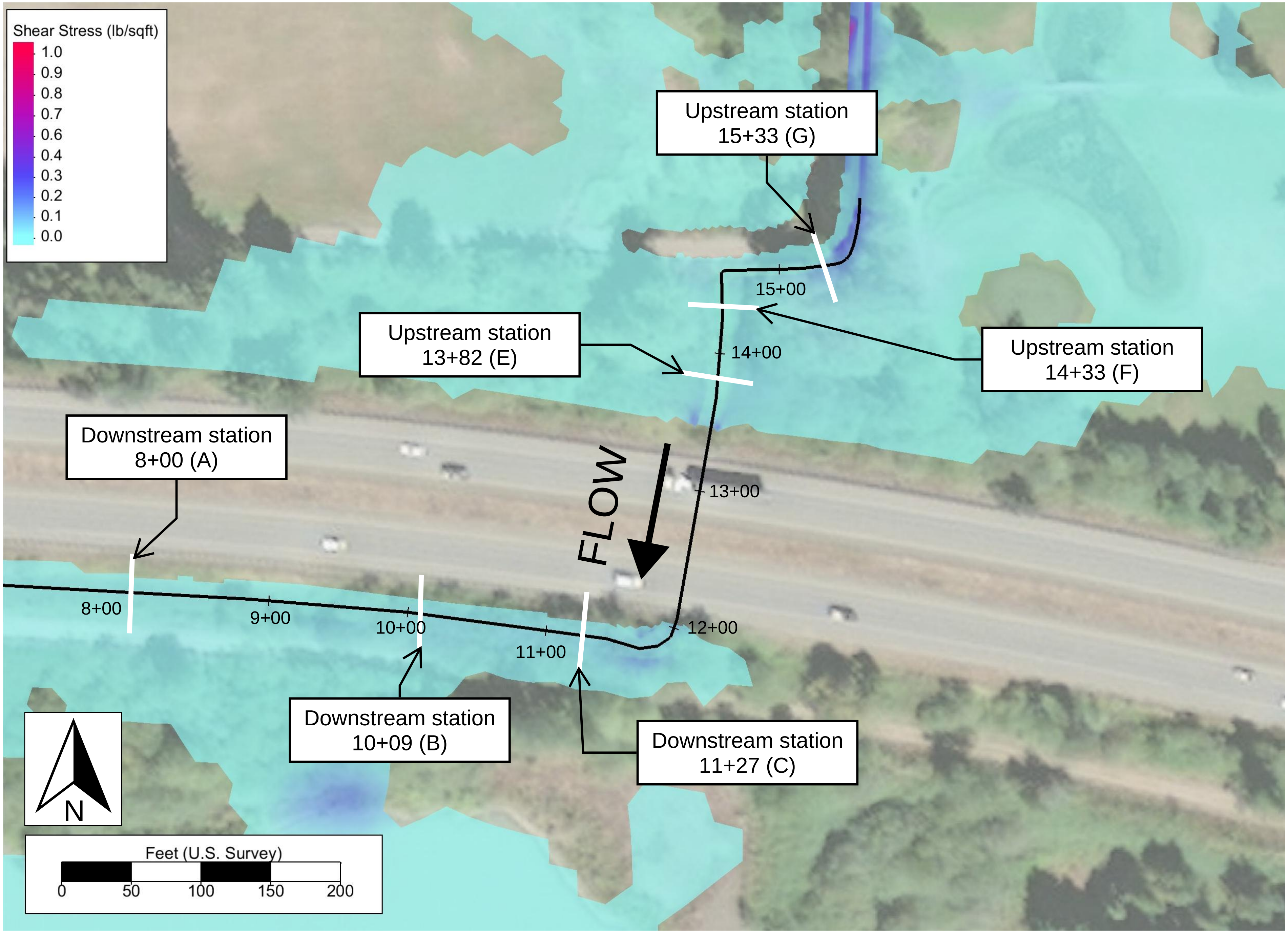

Figure H.4: Existing conditions 2-year shear stress

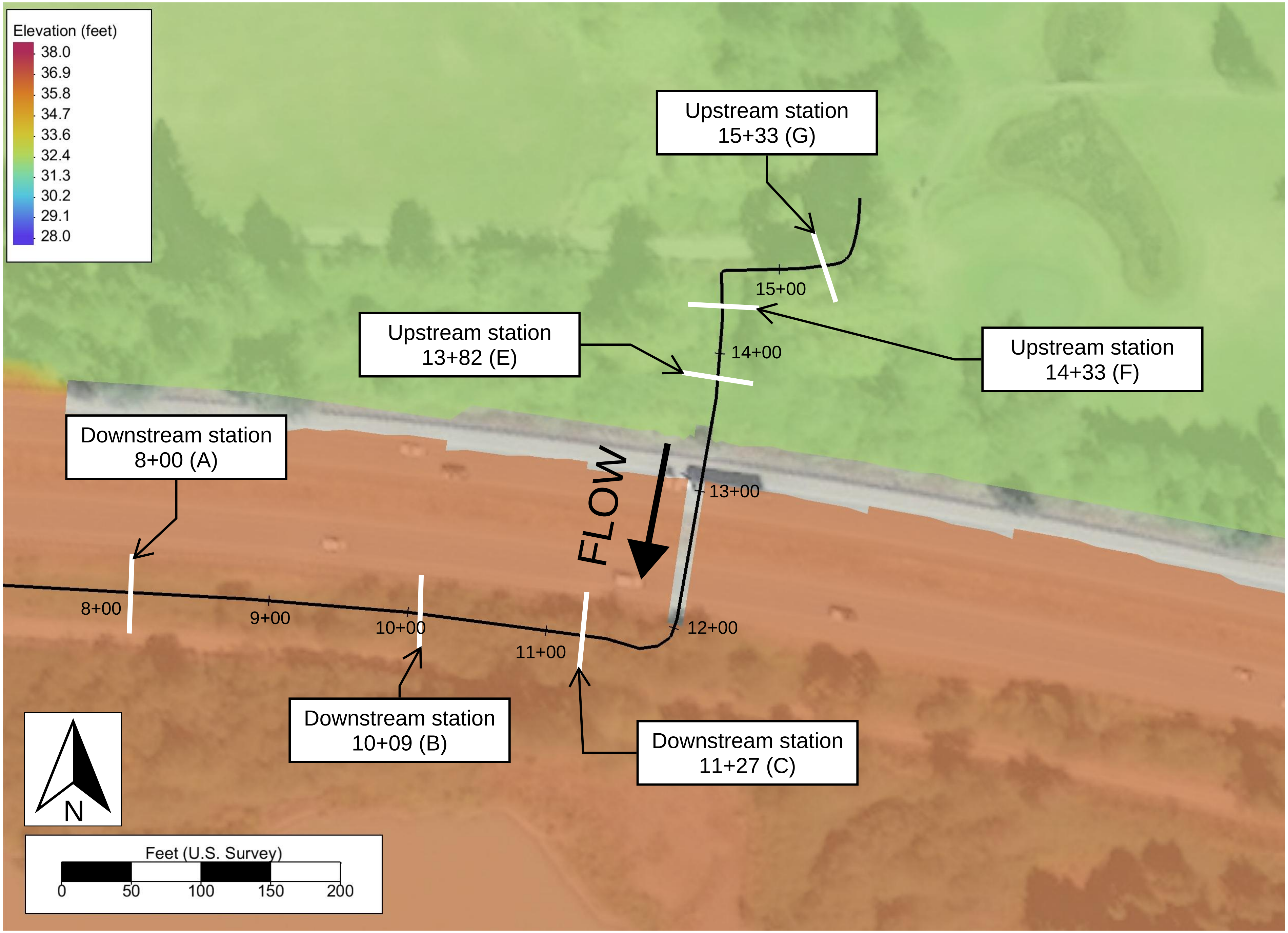

Figure H.5: Existing conditions 2-year with 100-year Chehalis water surface elevation

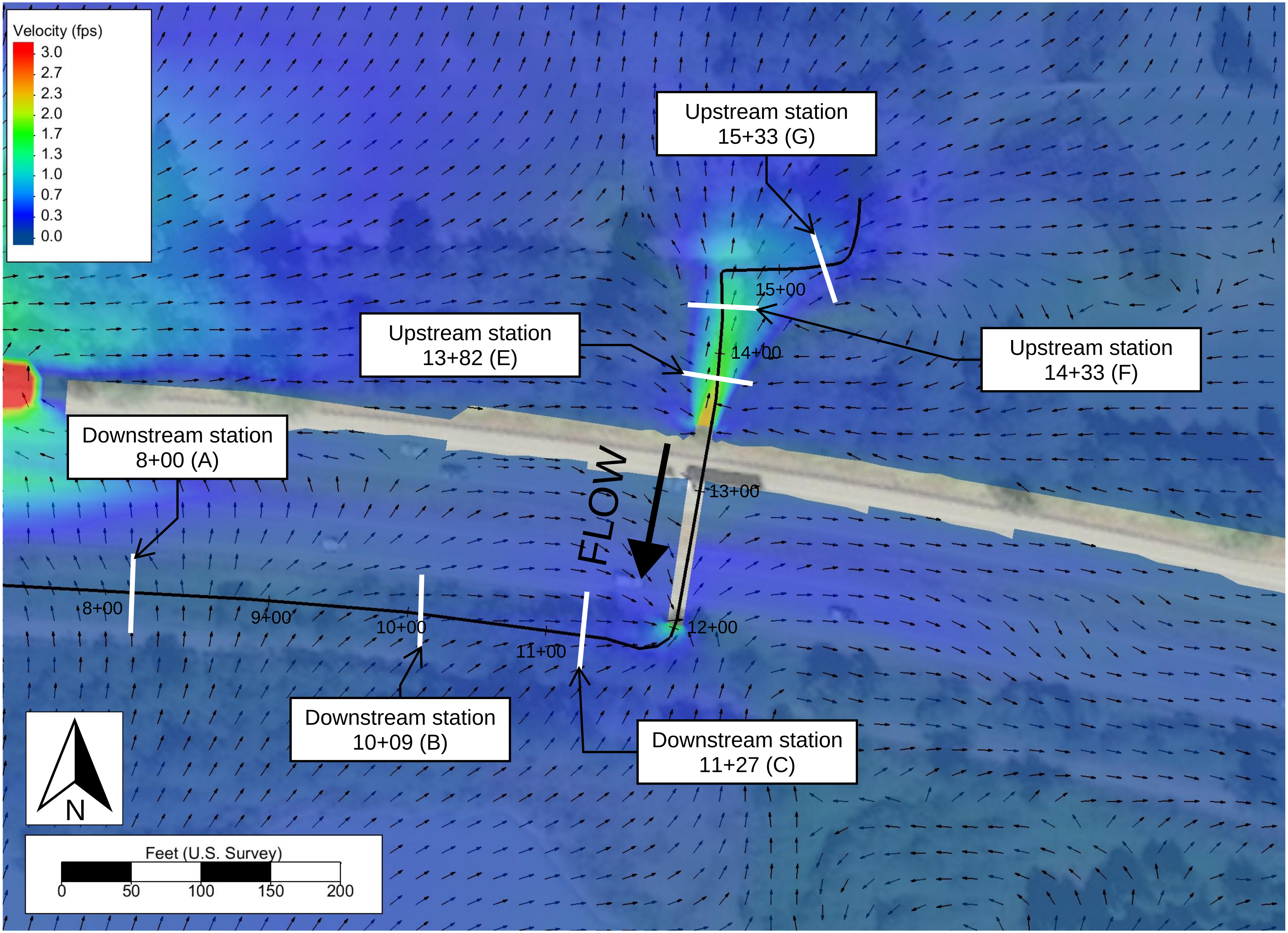

Figure H.6: Existing conditions 2-year with 100-year Chehalis velocity

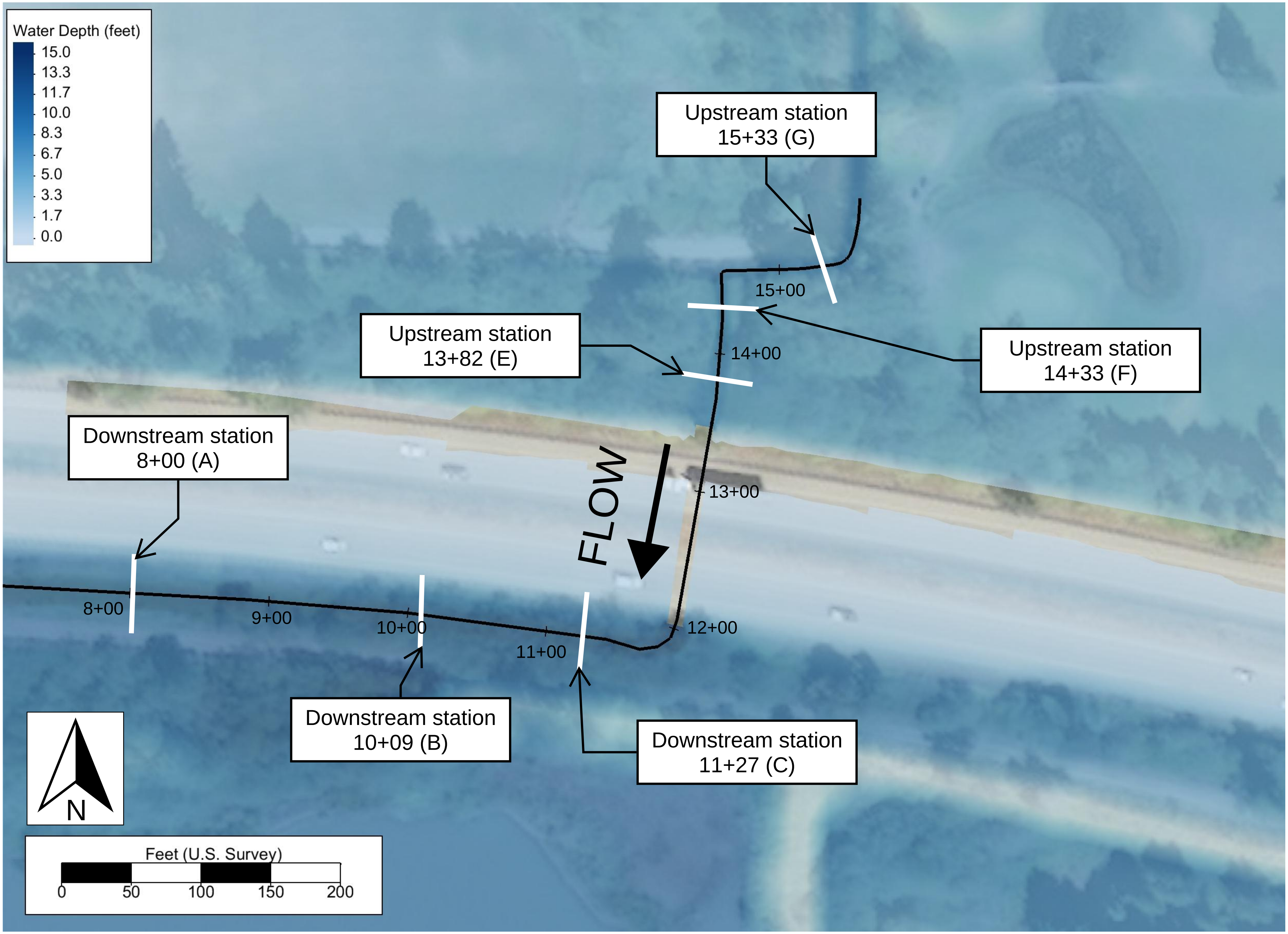

Figure H.7: Existing conditions 2-year with 100-year Chehalis water depth

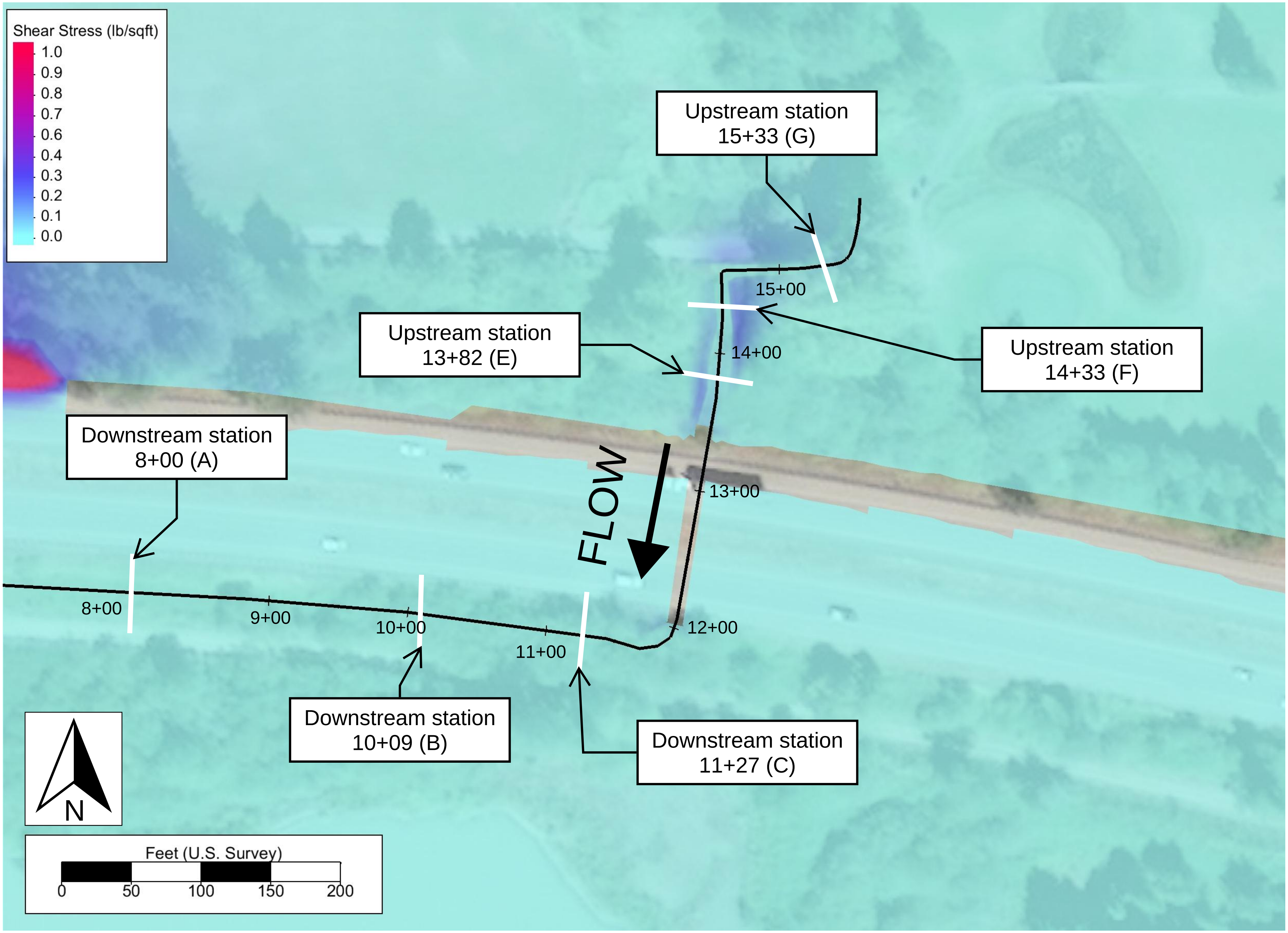

Figure H.8: Existing conditions 2-year with 100-year Chehalis shear stress

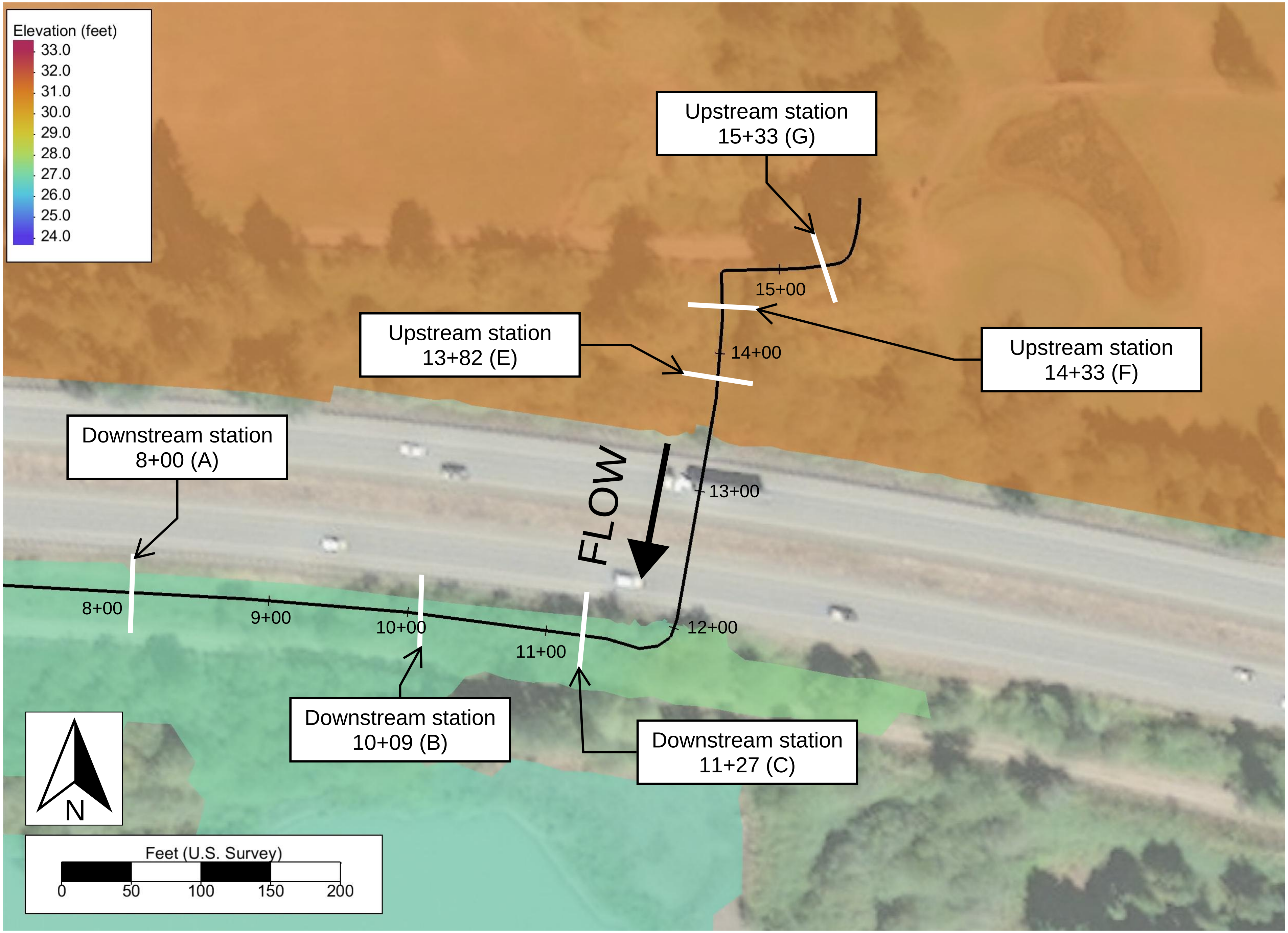

Figure H.9: Existing conditions 100-year water surface elevation

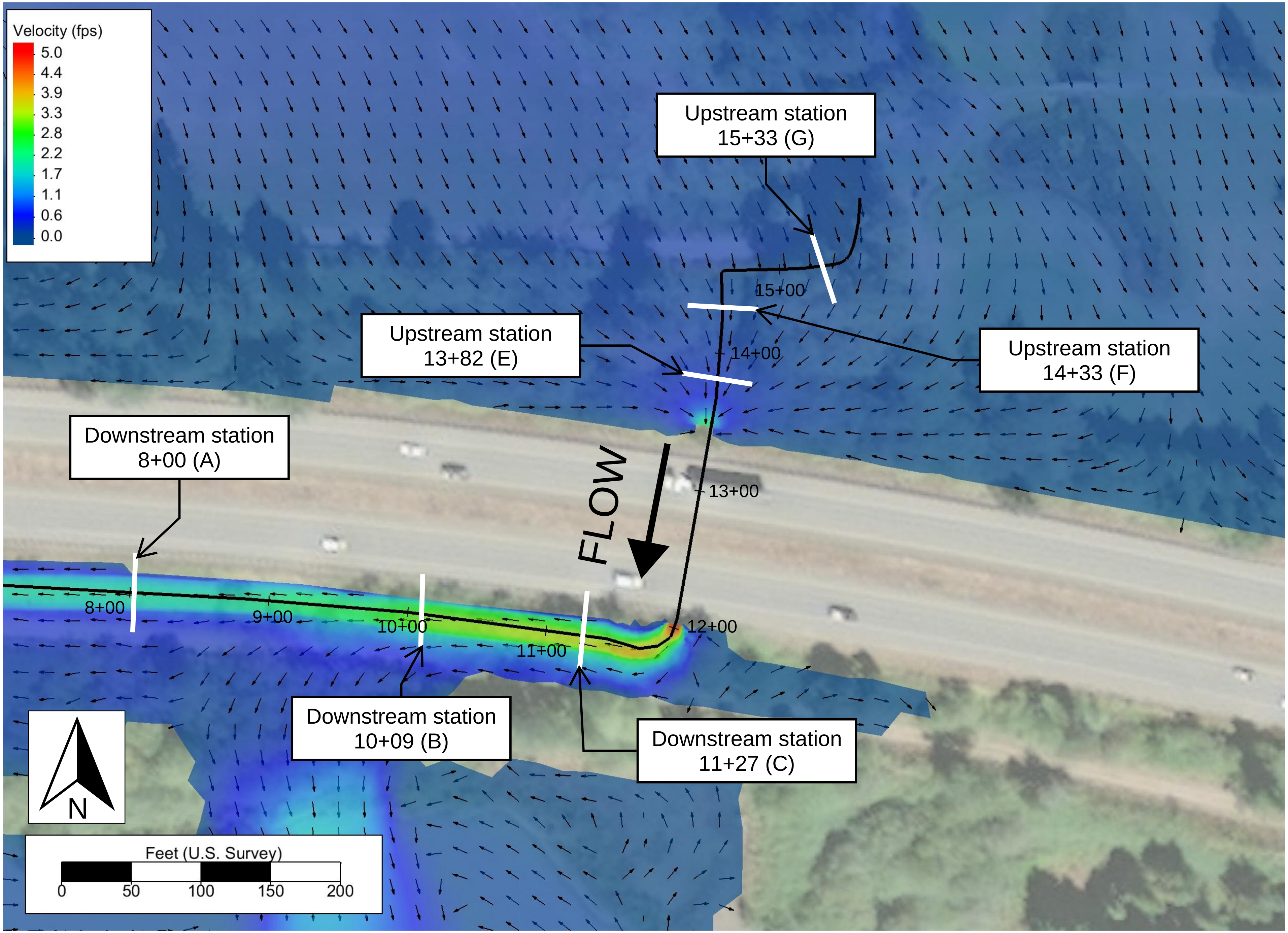

Figure H.10: Existing conditions 100-year velocity

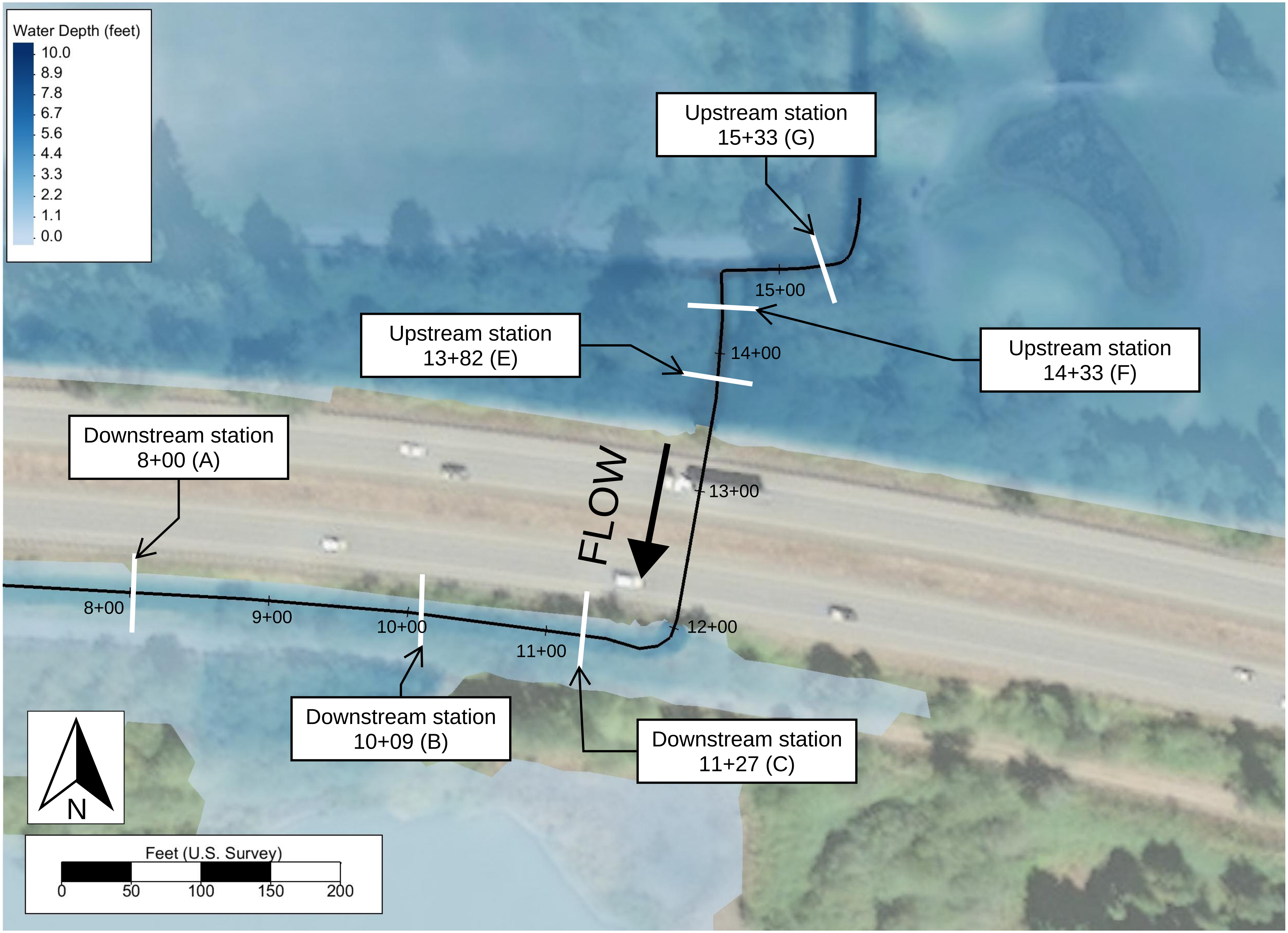

Figure H.11: Existing conditions 100-year water depth

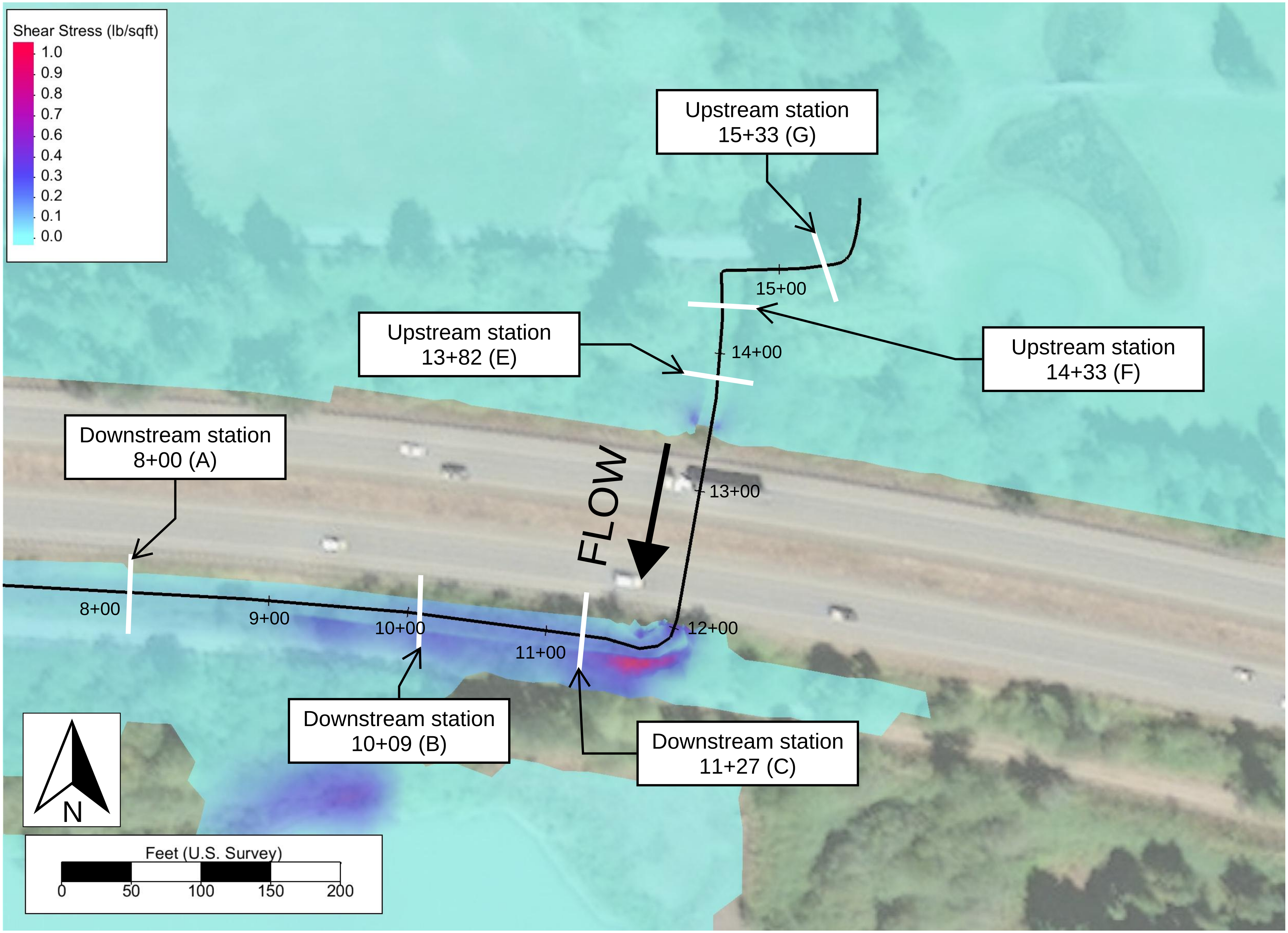

Figure H.12: Existing conditions 100-year shear stress

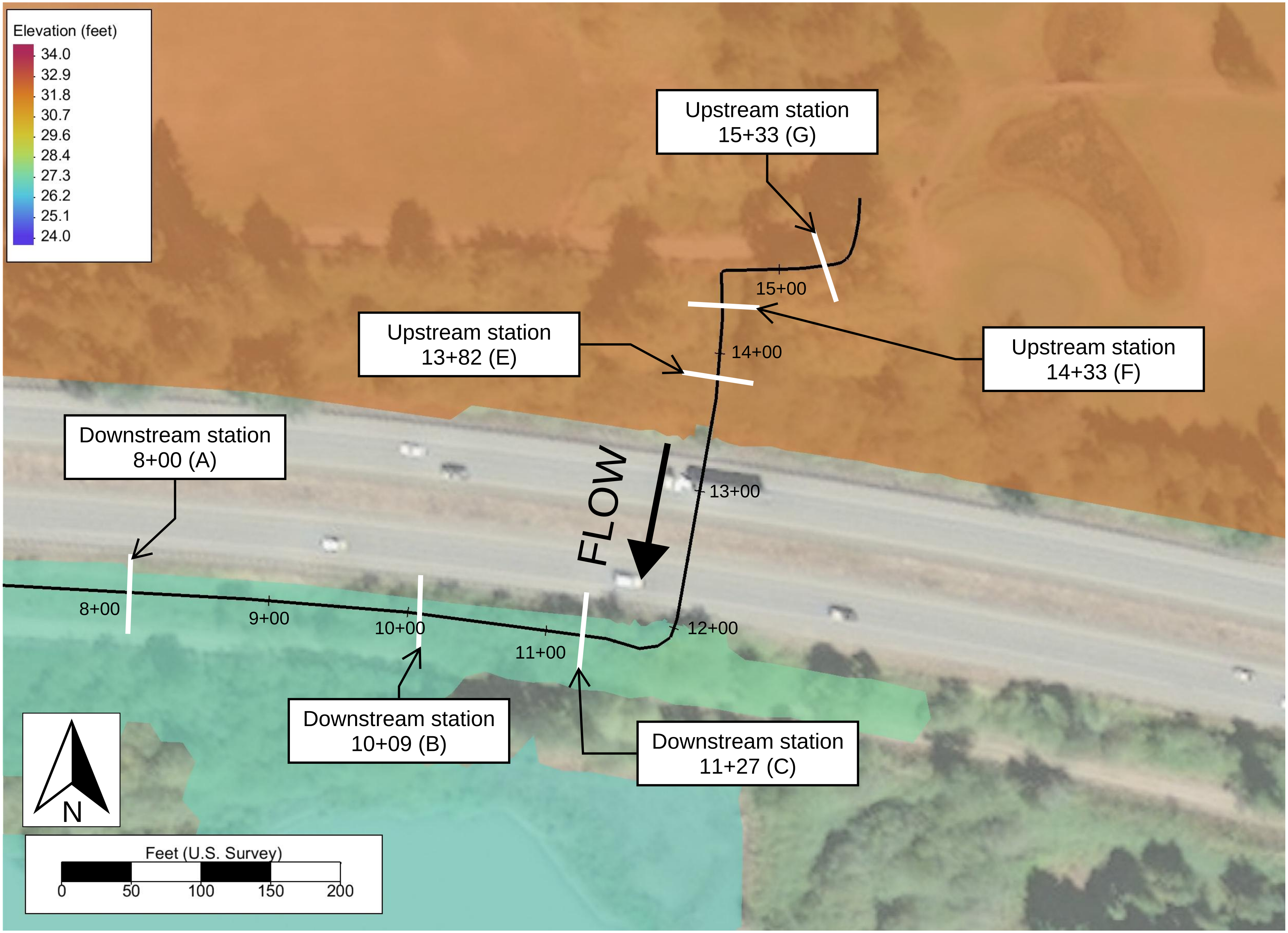

Figure H.13: Existing conditions 500-year water surface elevation

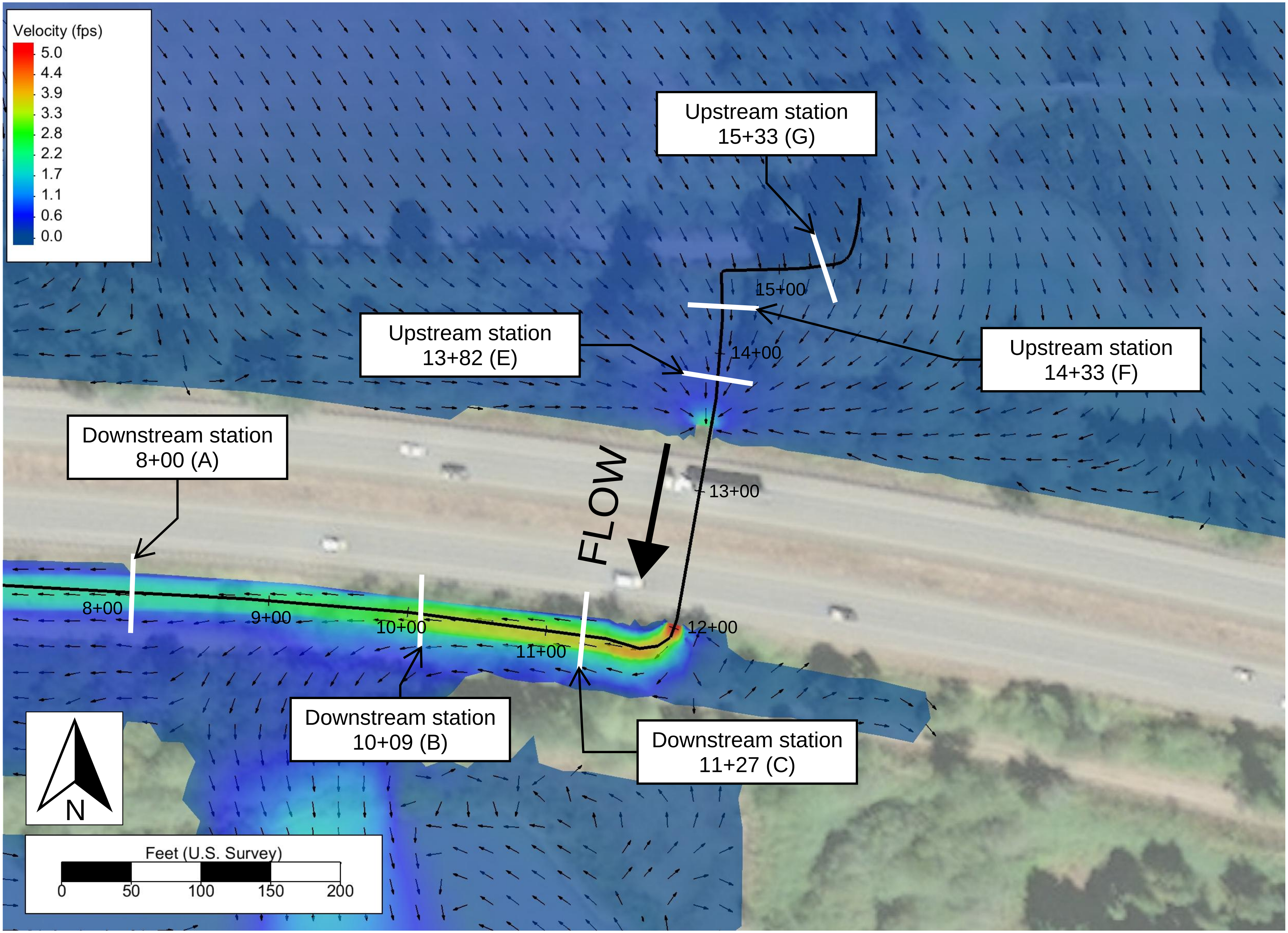

Figure H.14: Existing conditions 500-year velocity

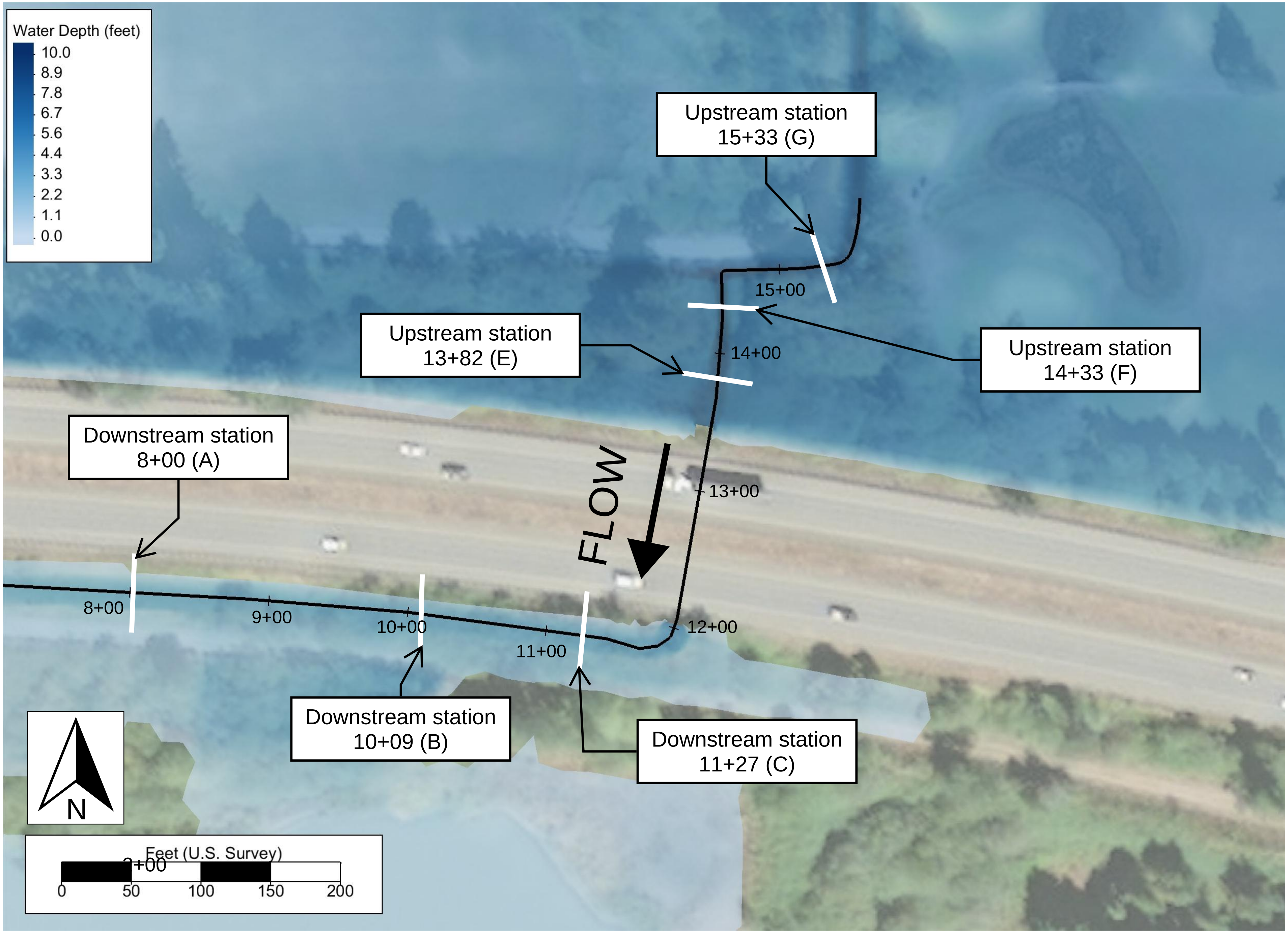

Figure H.15: Existing conditions 500-year water depth

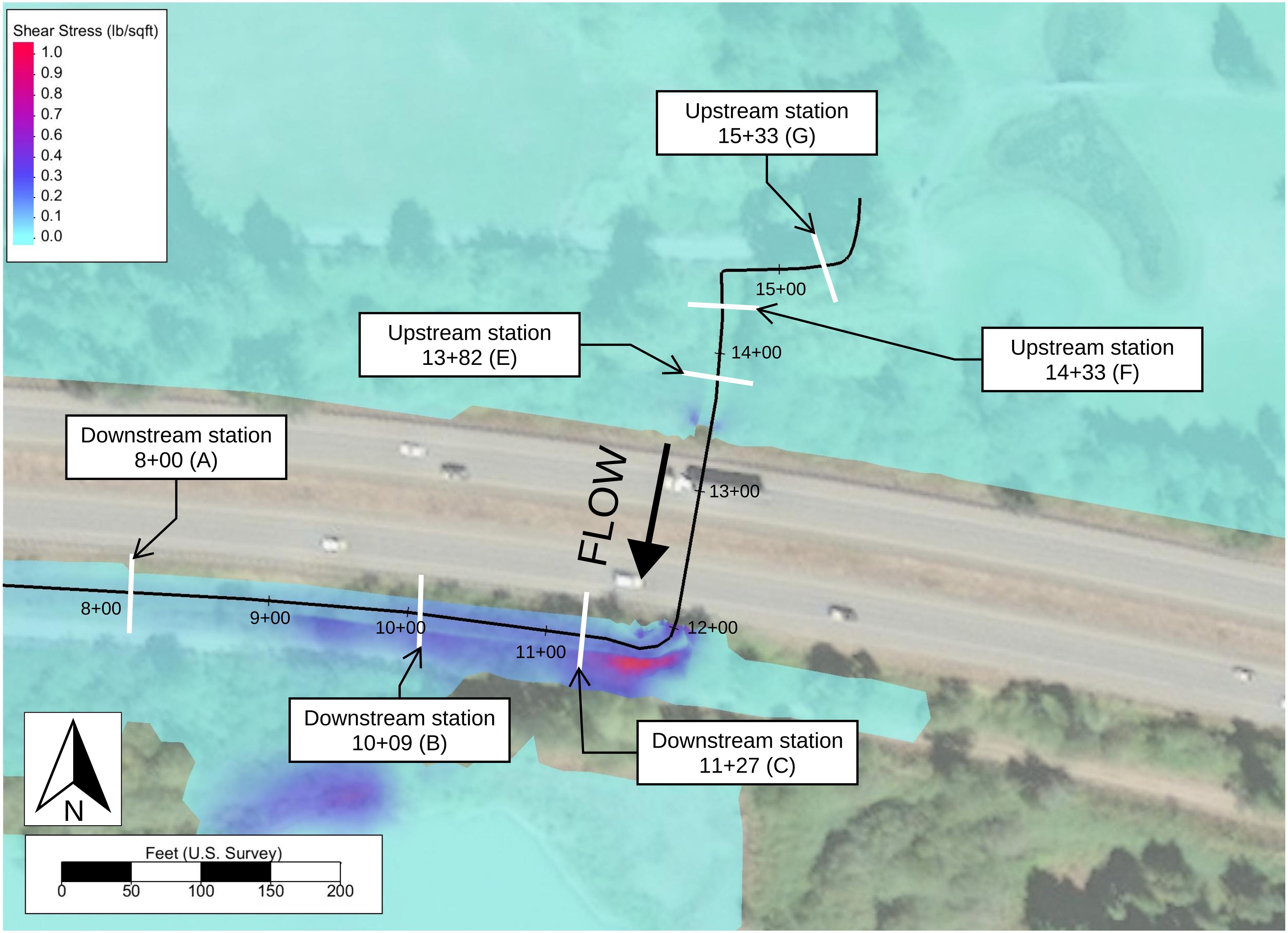

Figure H.16: Existing conditions 500-year shear stress

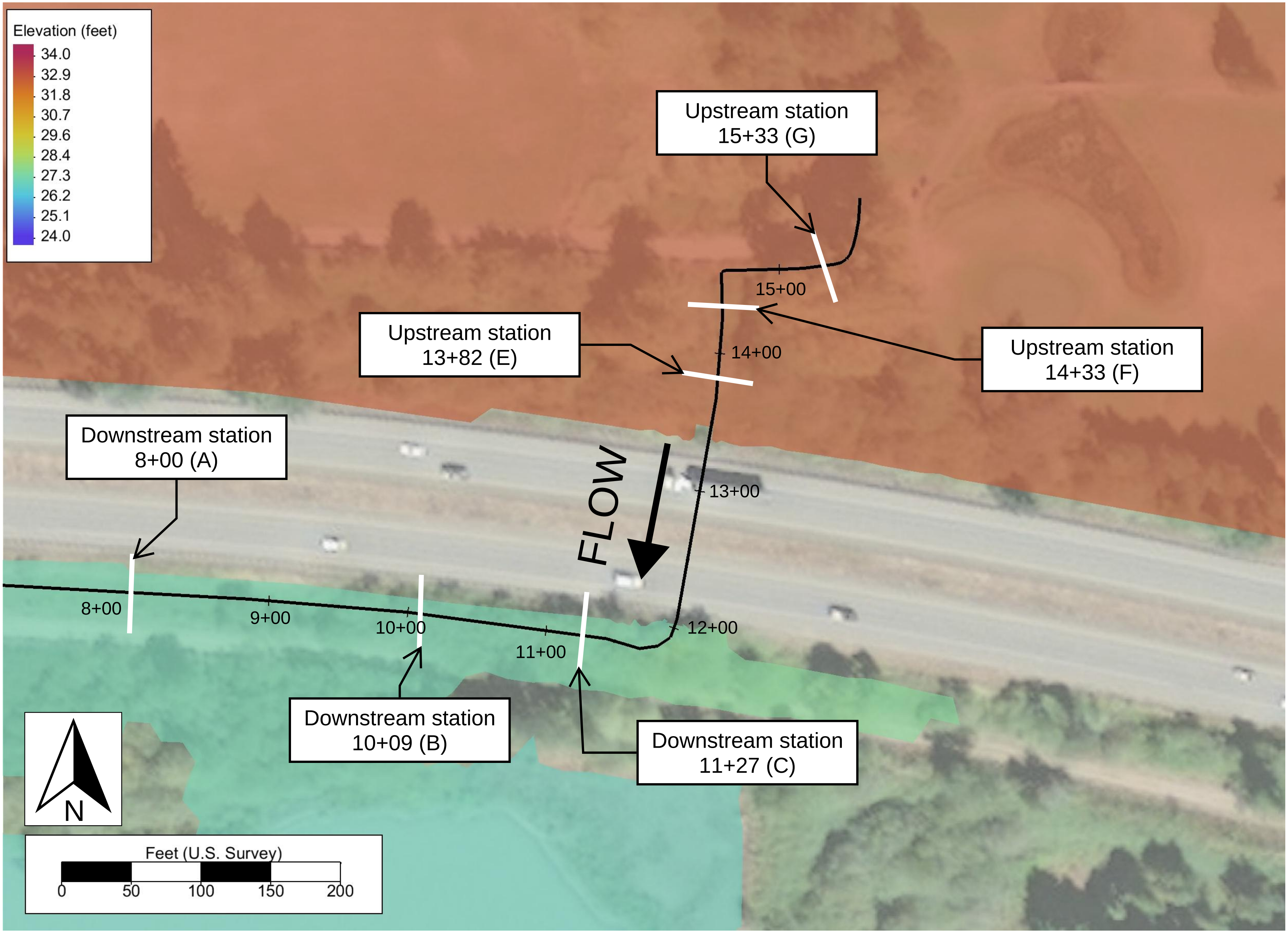

Figure H.17: Existing conditions 2080 predicted 100-year water surface elevation

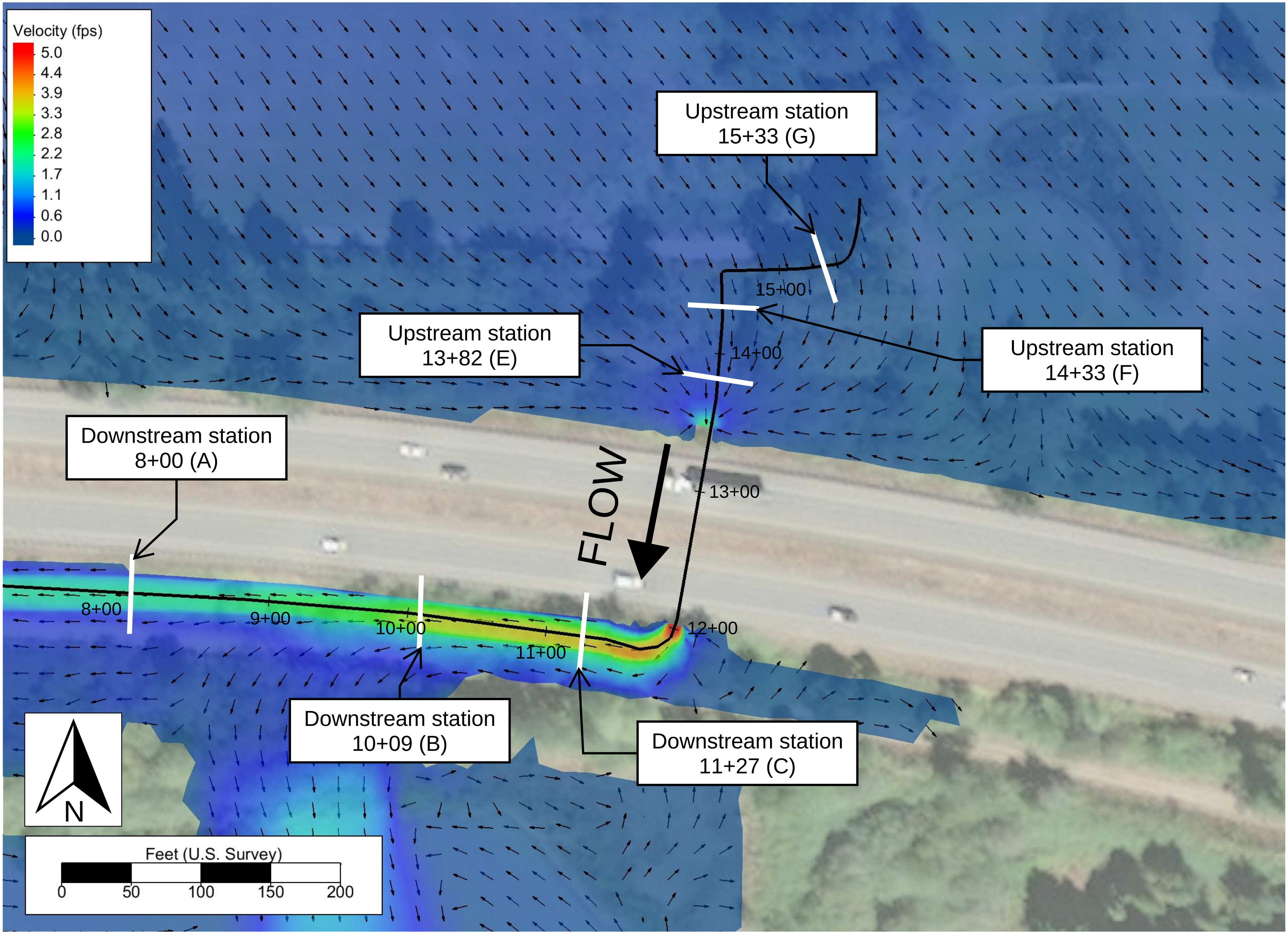

Figure H.18: Existing conditions 2080 predicted 100-year velocity

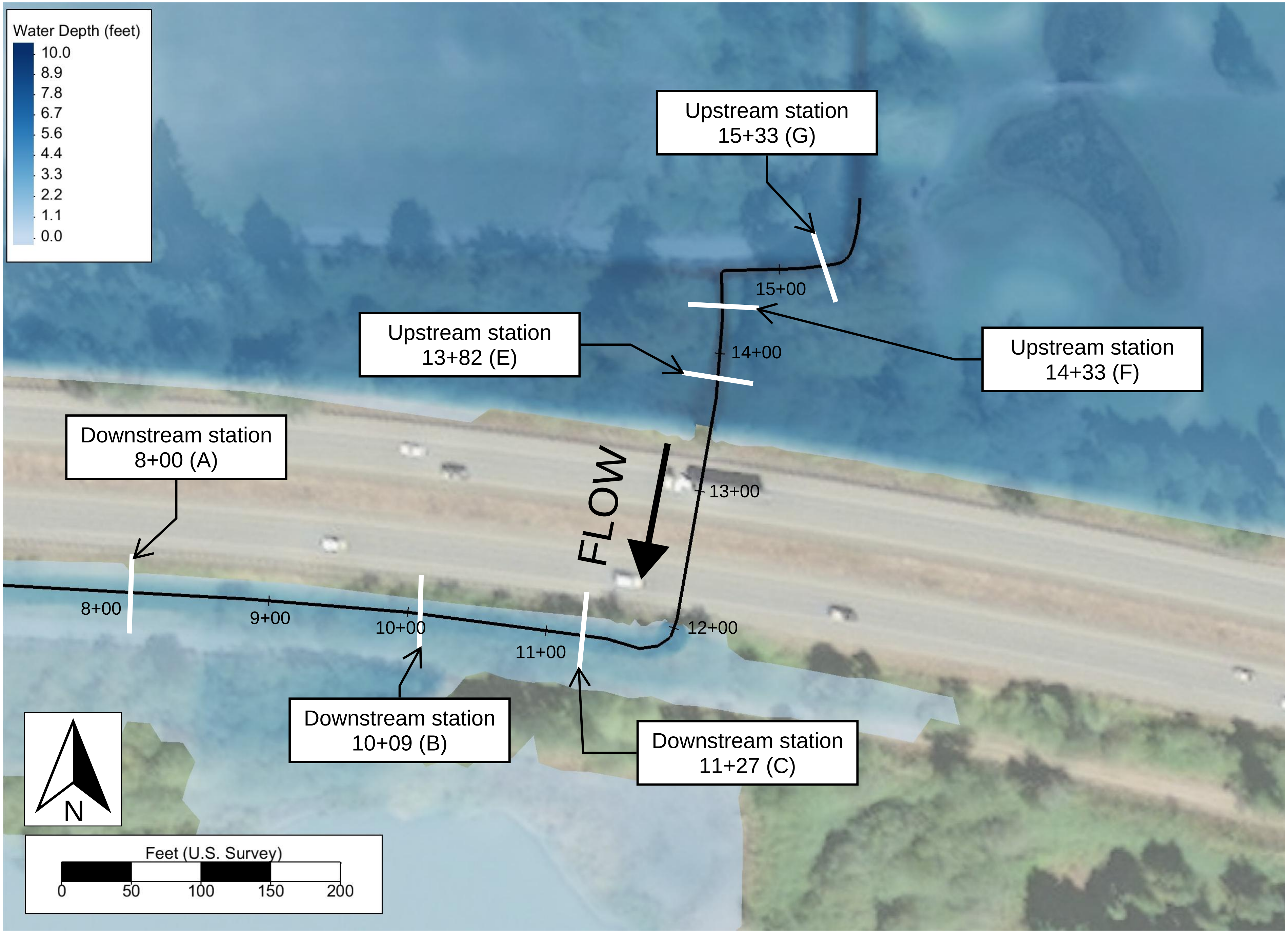

Figure H.19: Existing conditions 2080 predicted 100-year water depth

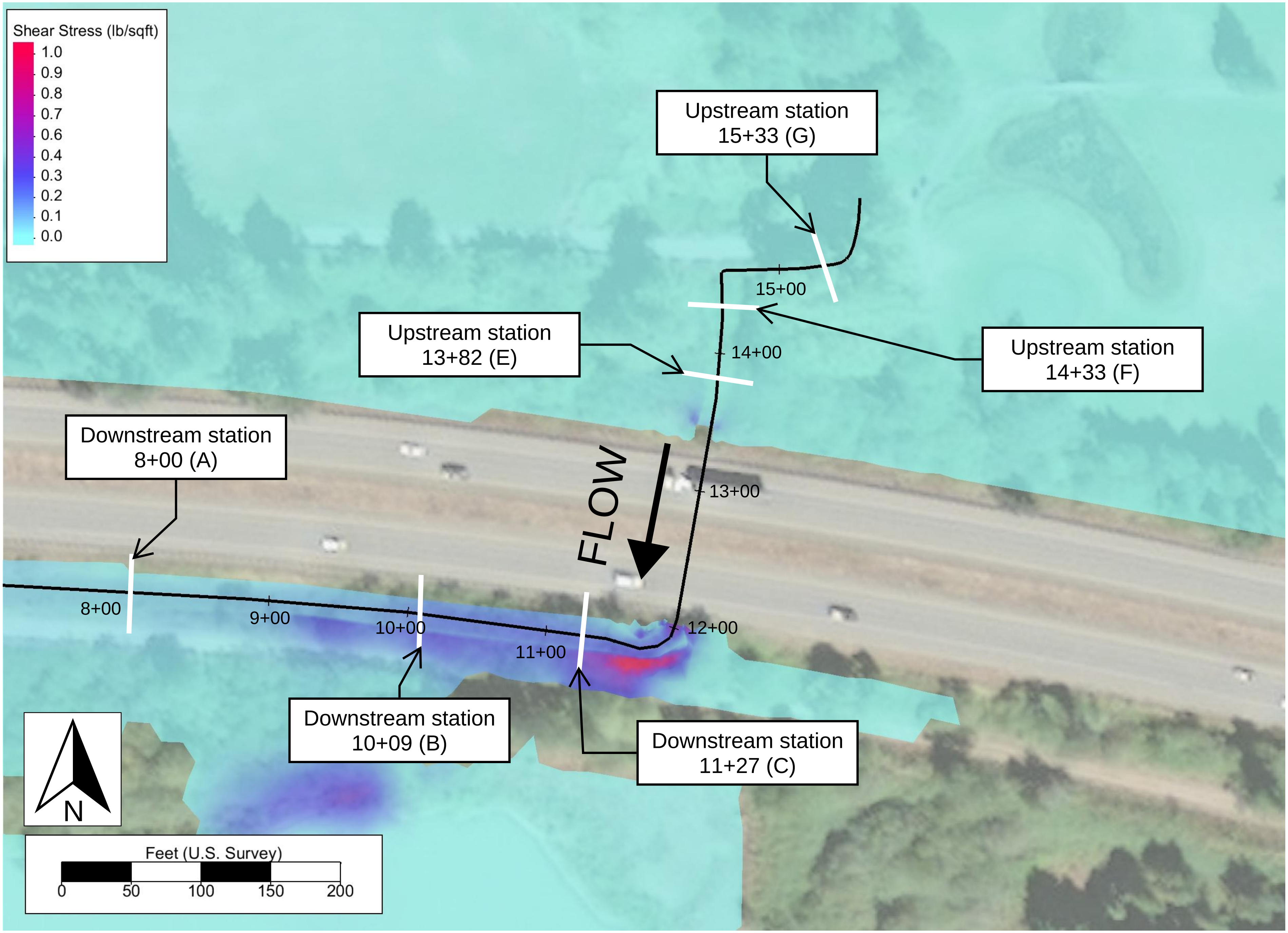

Figure H.20: Existing conditions 2080 predicted 100-year shear stress

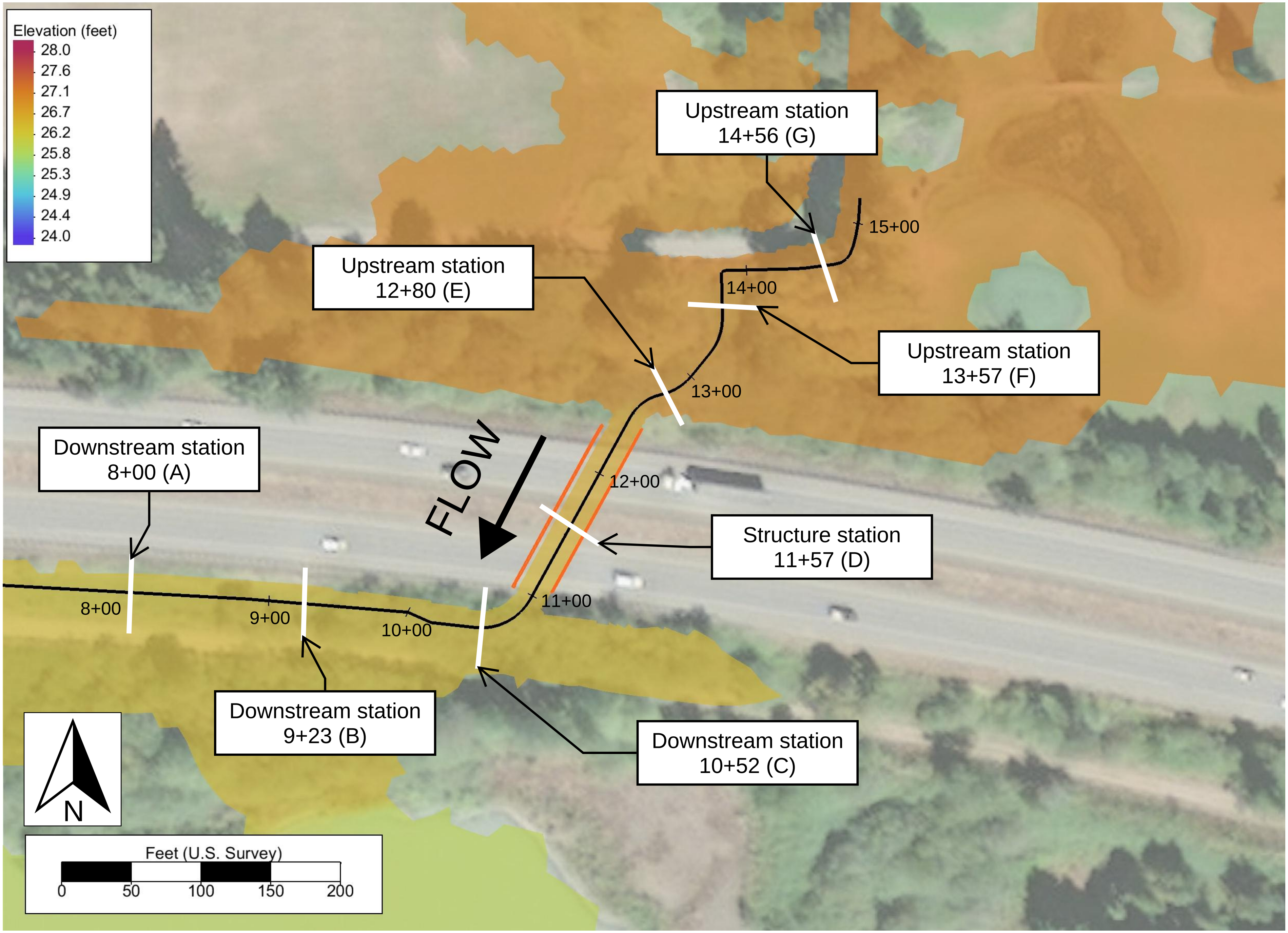

Figure H.21: Proposed conditions 2-year water surface elevation

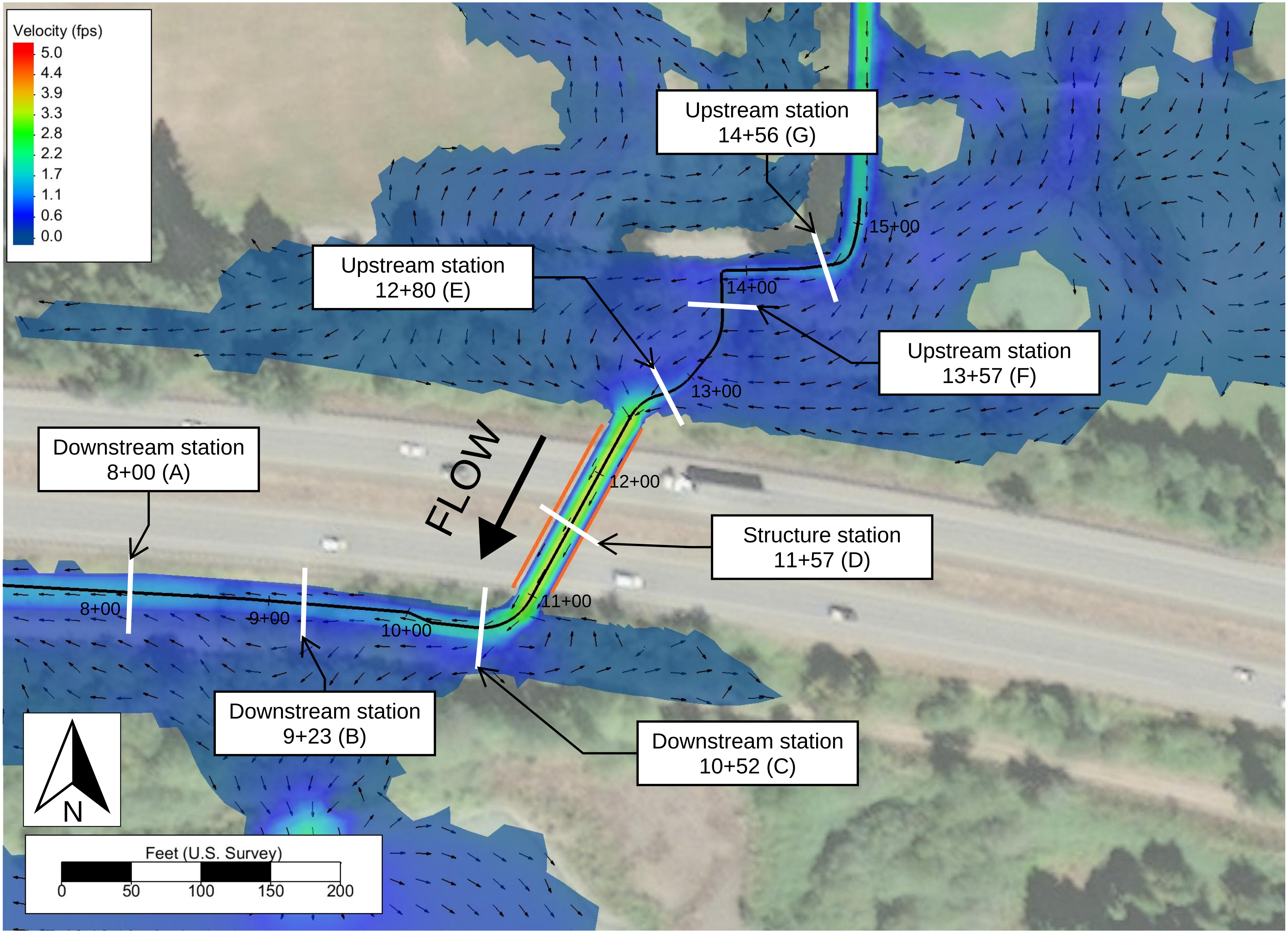

Figure H.22: Proposed conditions 2-year velocity

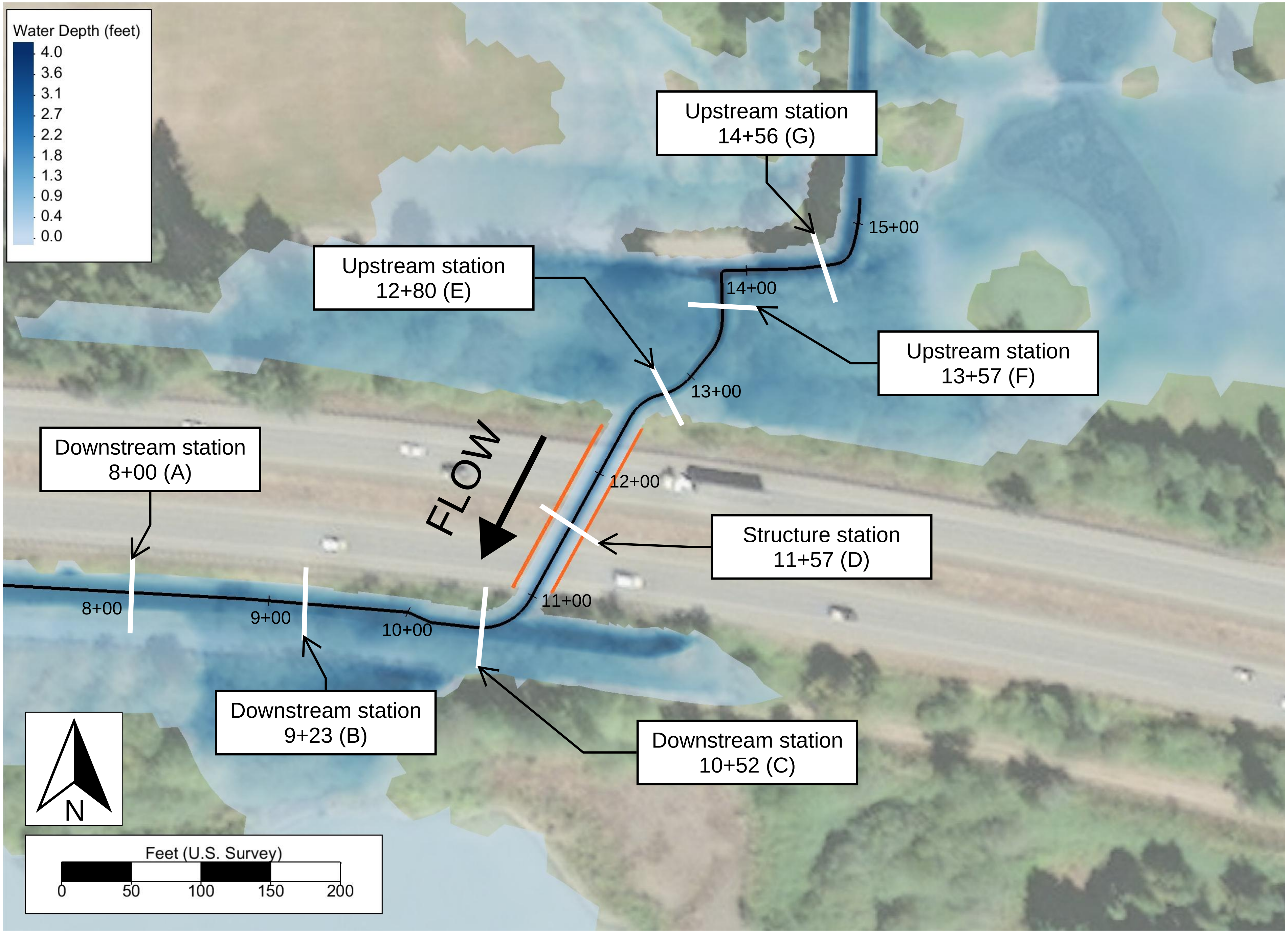

Figure H.23: Proposed conditions 2-year water depth

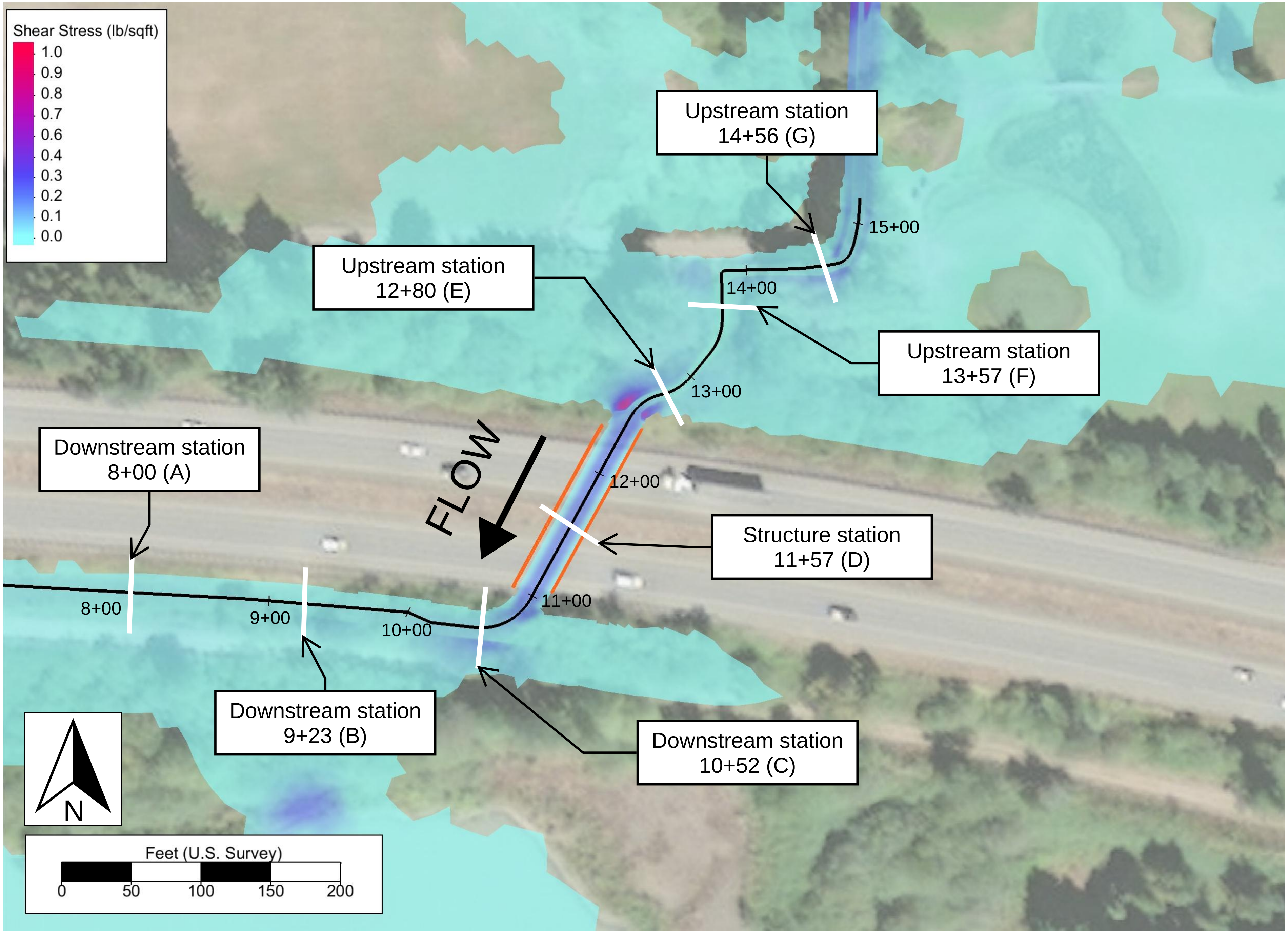

Figure H.24: Proposed conditions 2-year shear stress

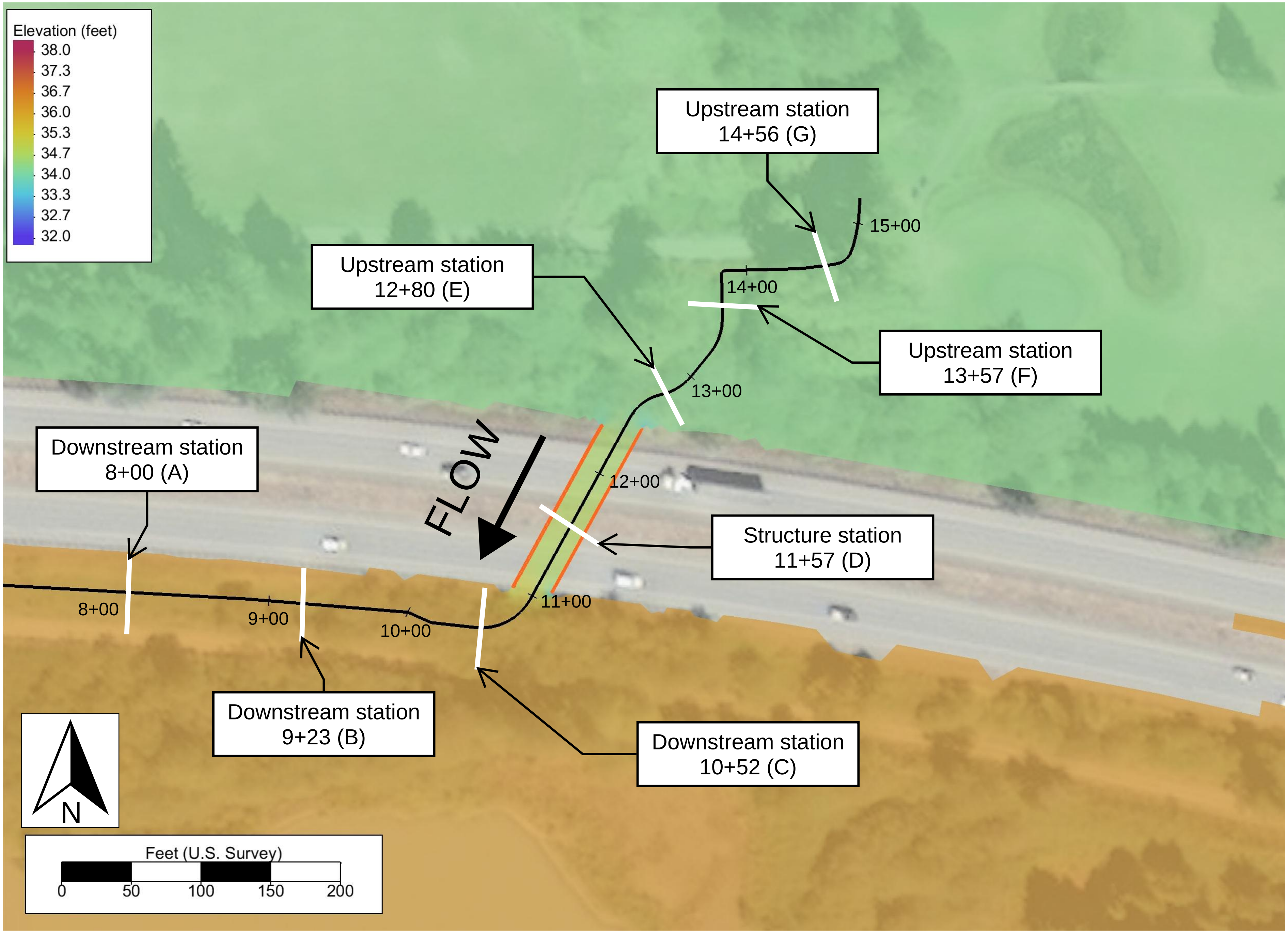

Figure H.25: Proposed conditions 2-year with 100-year Chehalis water surface elevation

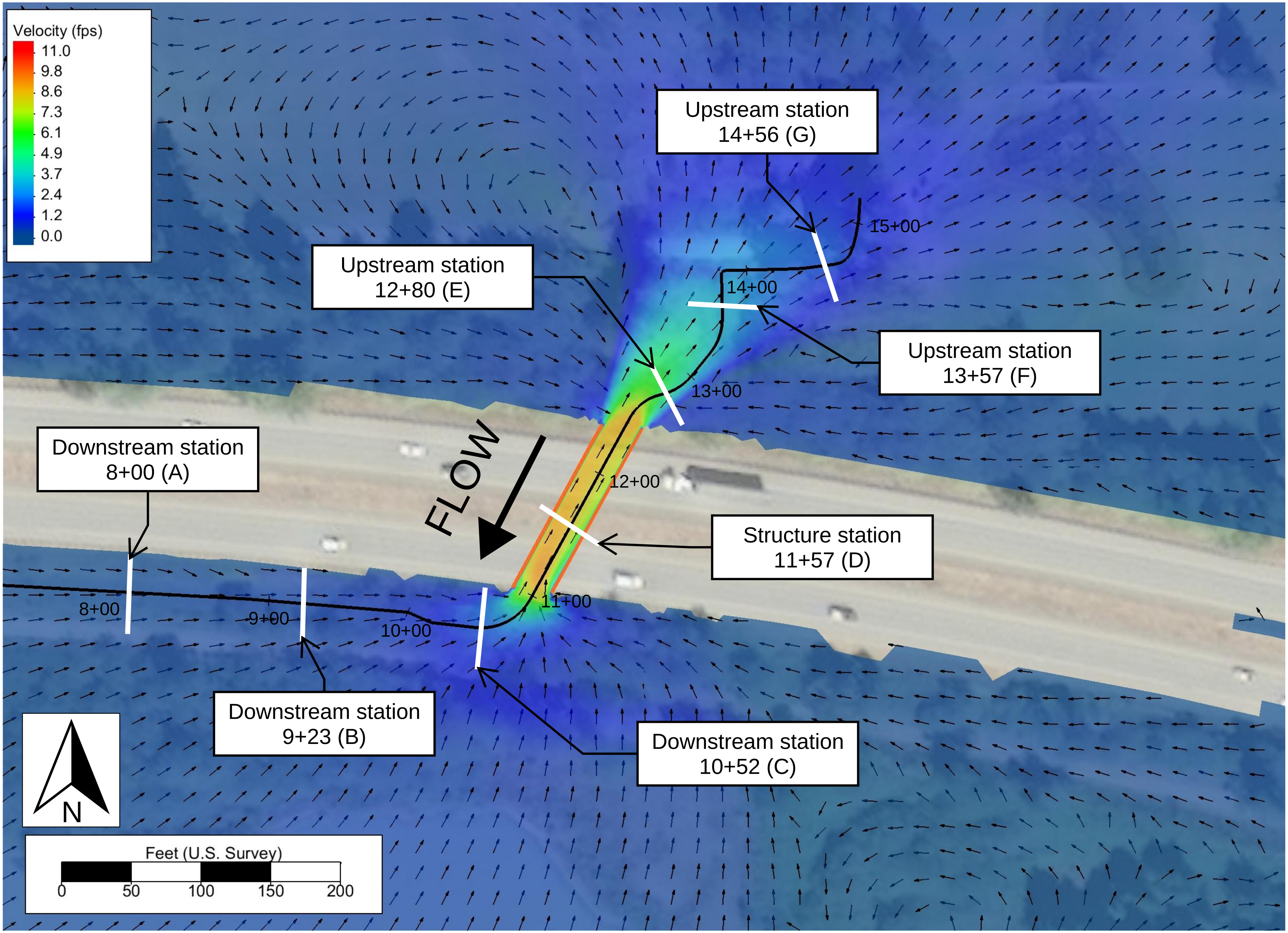

Figure H.26: Proposed conditions 2-year with 100-year Chehalis velocity

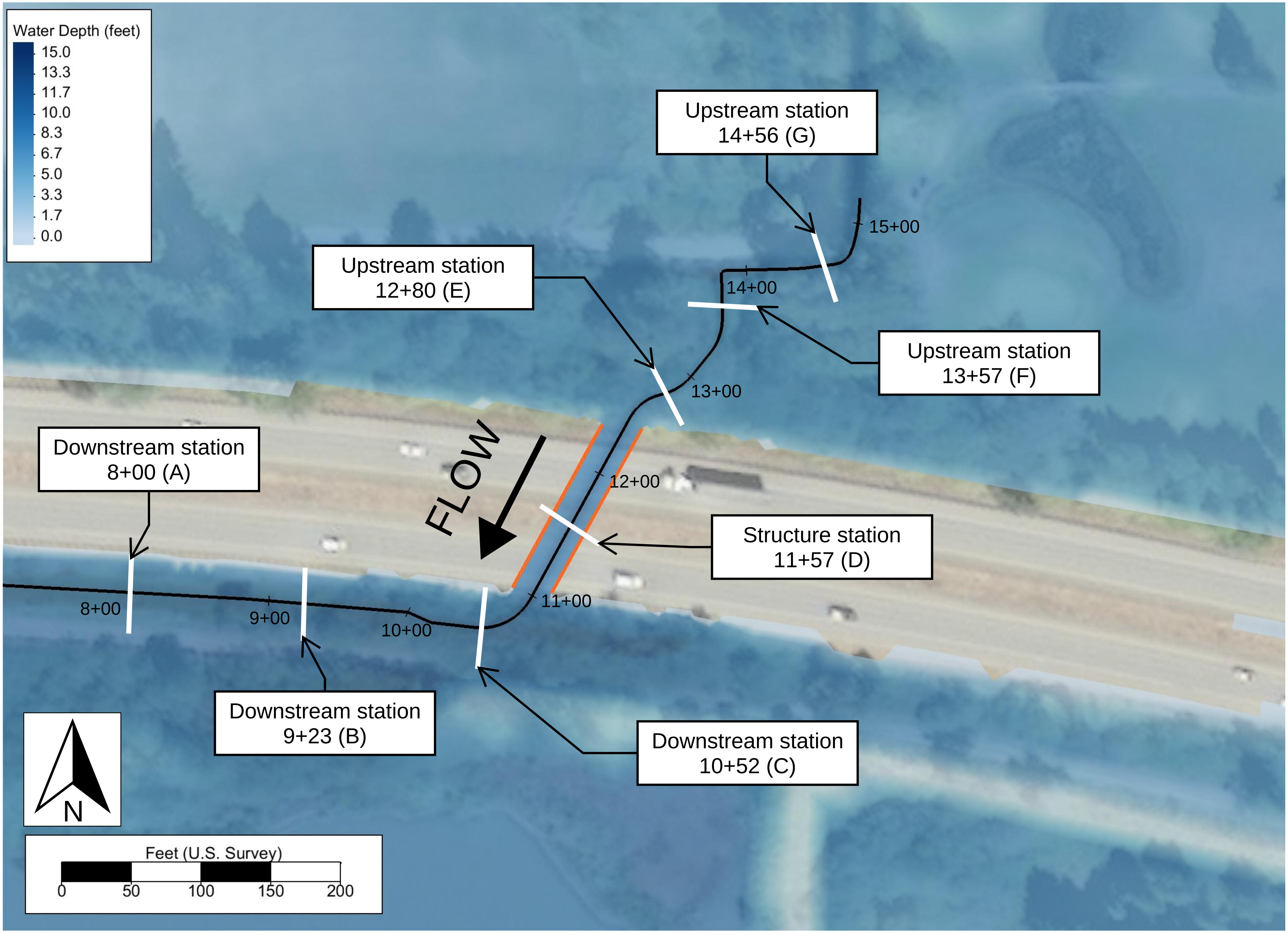

Figure H.27: Proposed conditions 2-year with 100-year Chehalis water depth

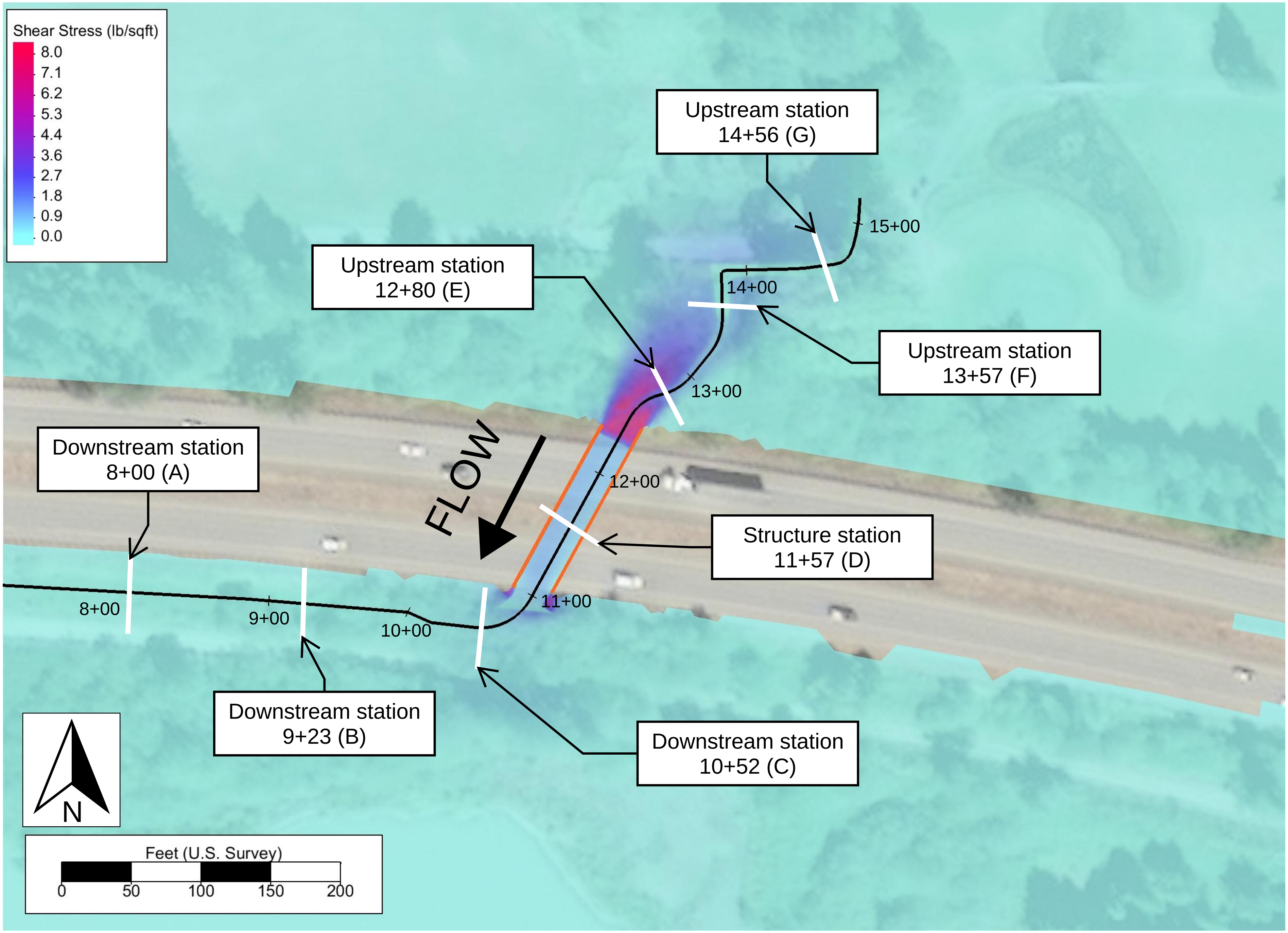

Figure H.28: Proposed conditions 2-year with 100-year Chehalis shear stress

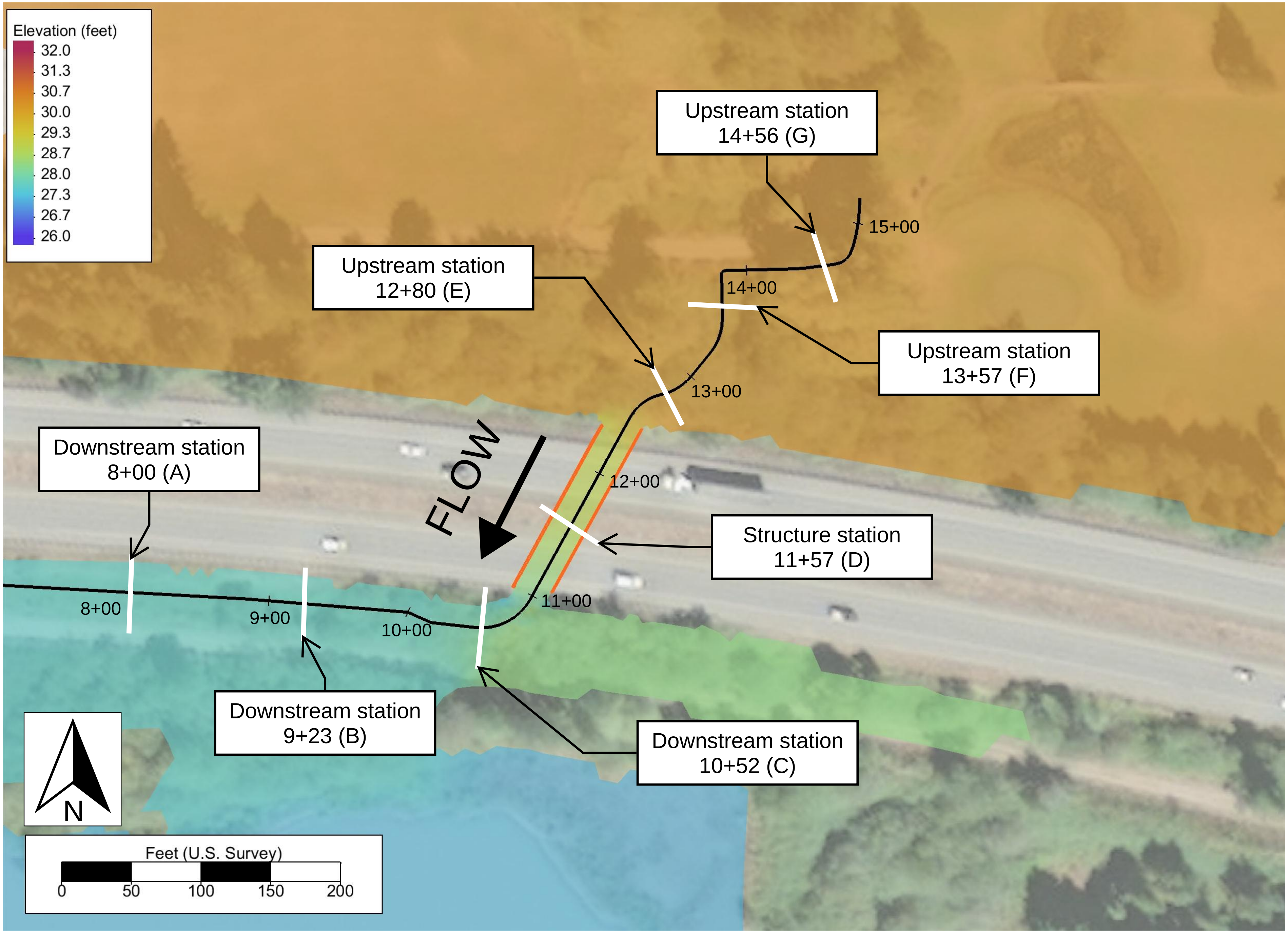

Figure H.29: Proposed conditions 100-year water surface elevation

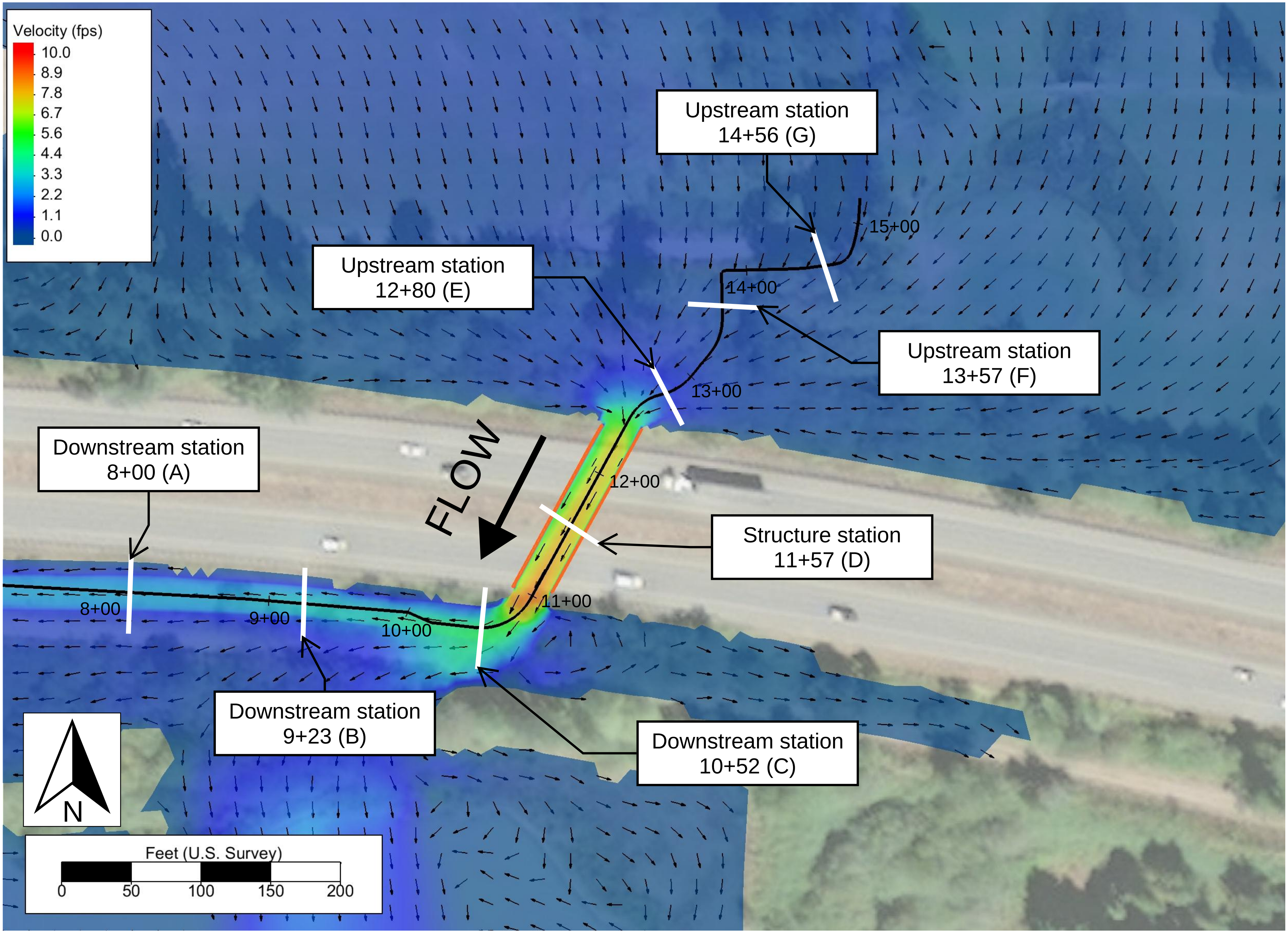

Figure H.30: Proposed conditions 100-year velocity

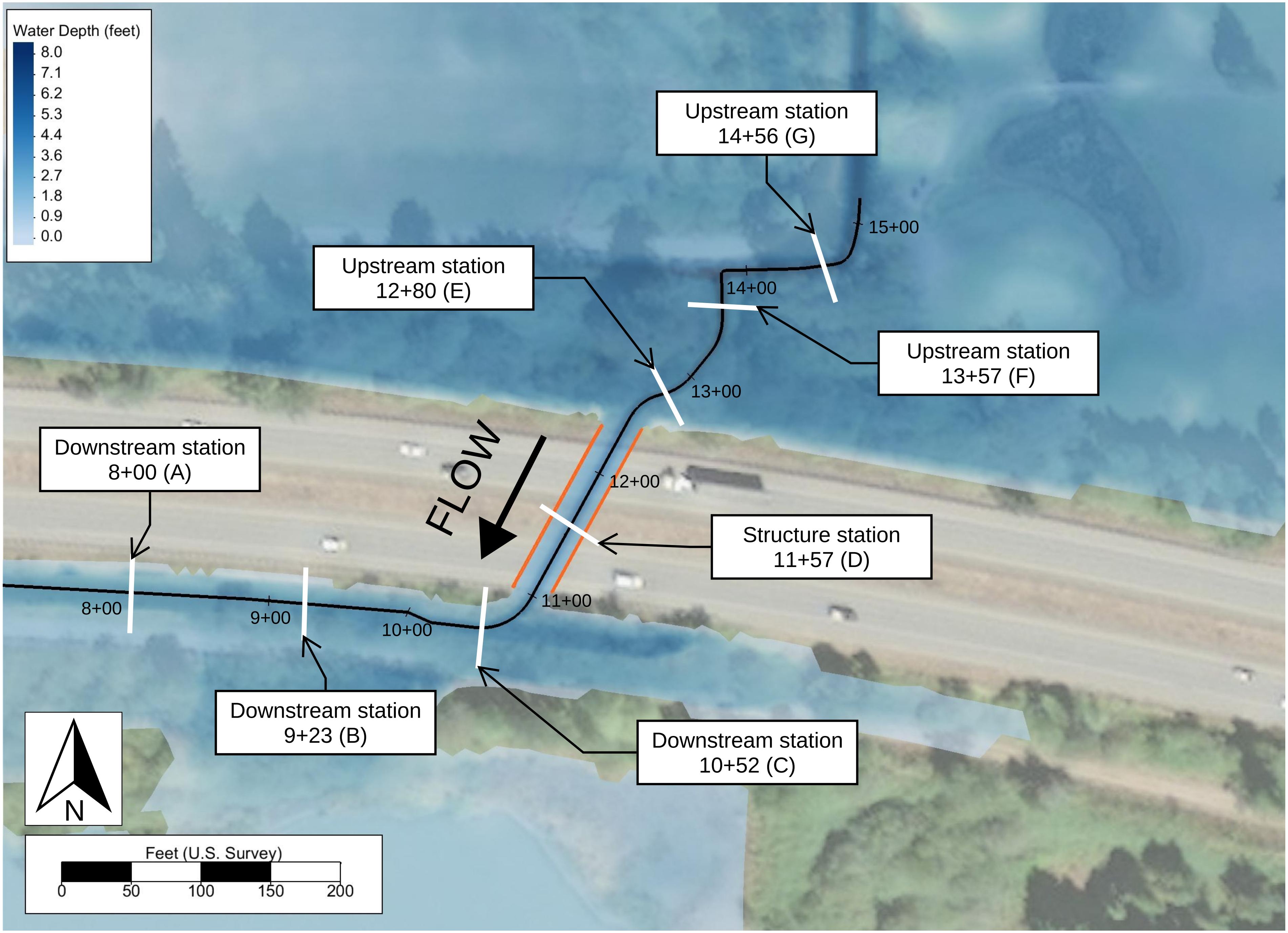

Figure H.31: Proposed conditions 100-year water depth

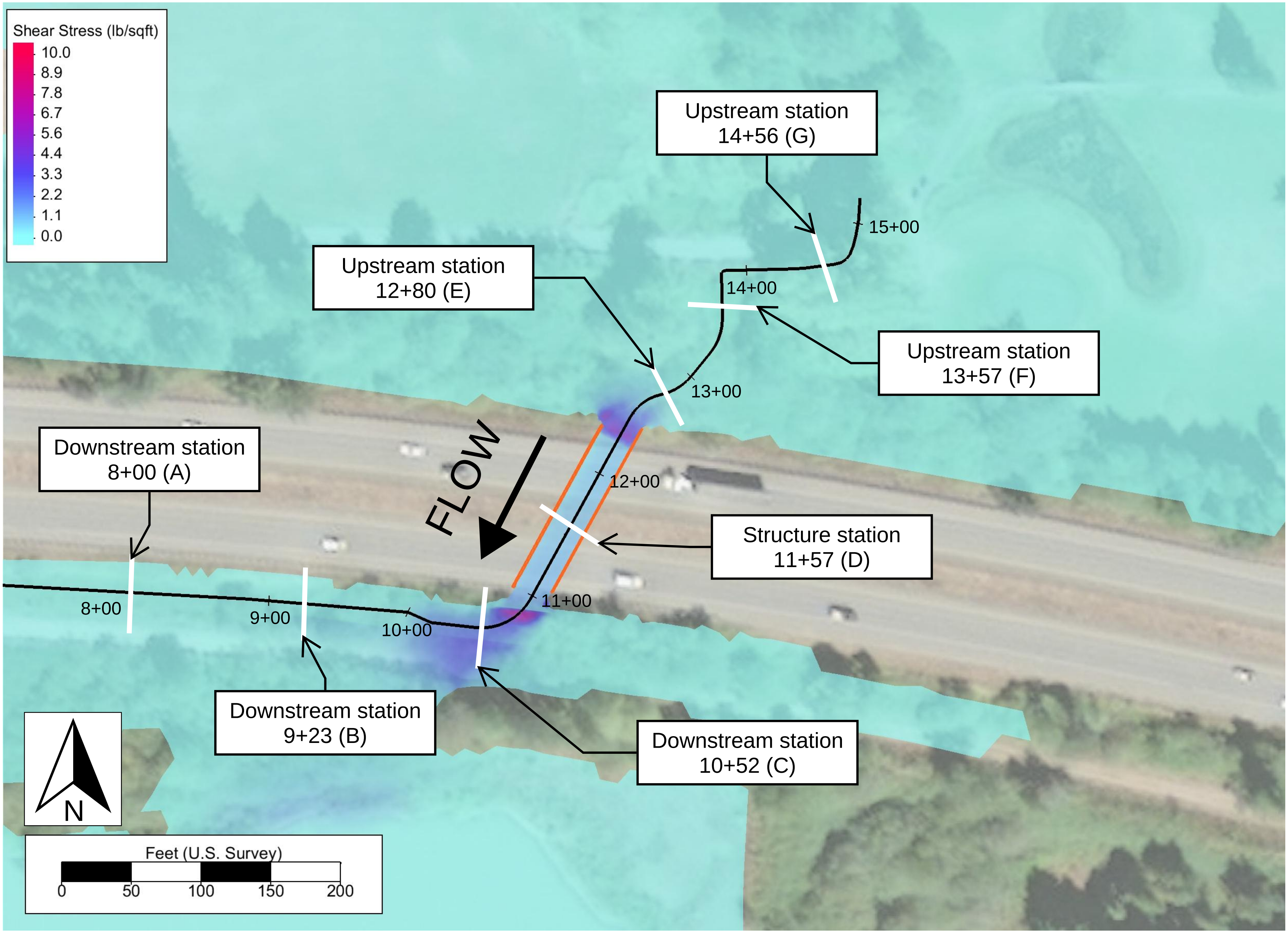

Figure H.32: Proposed conditions 100-year shear stress

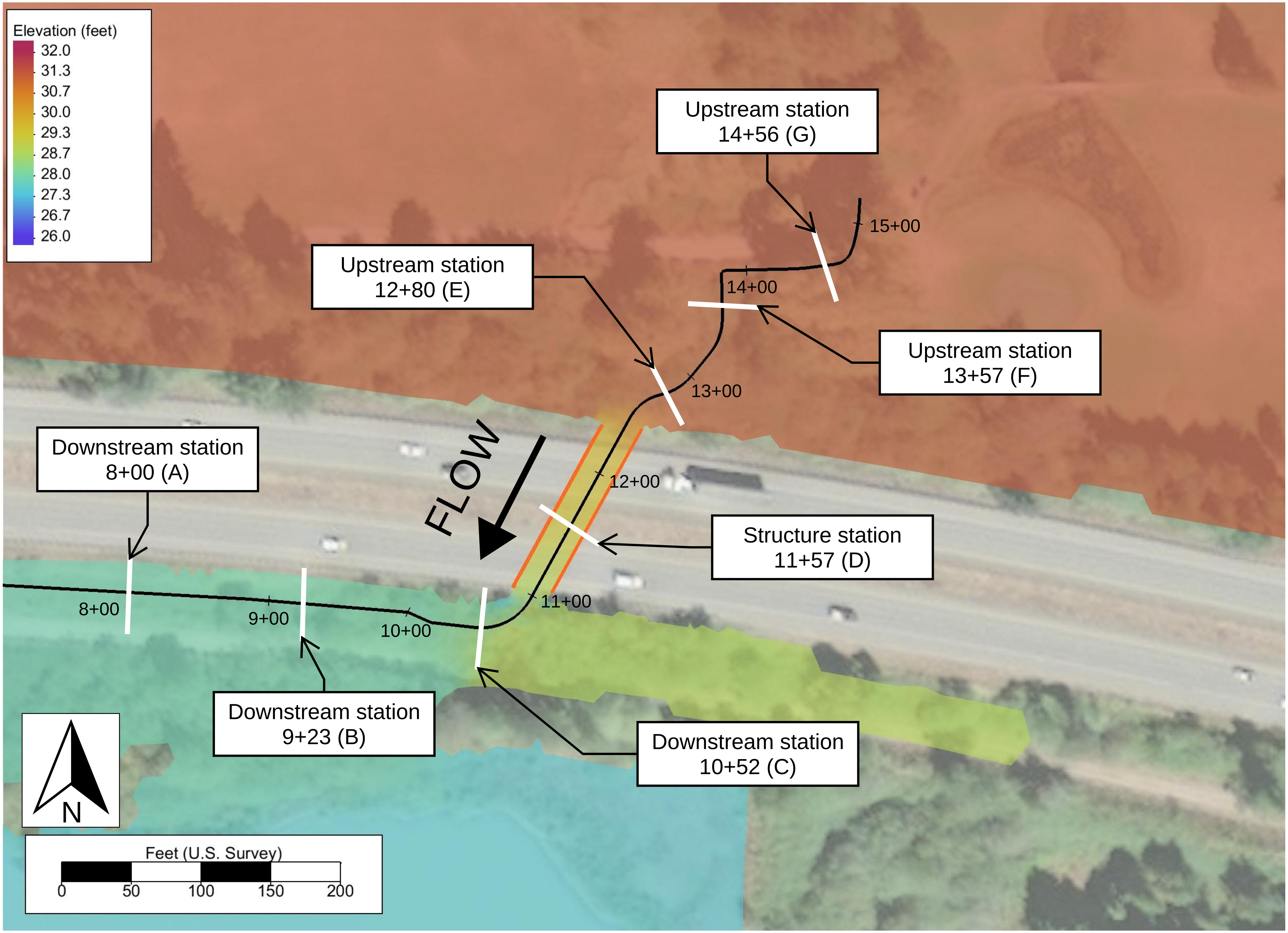

Figure H.33: Proposed conditions 500-year water surface elevation

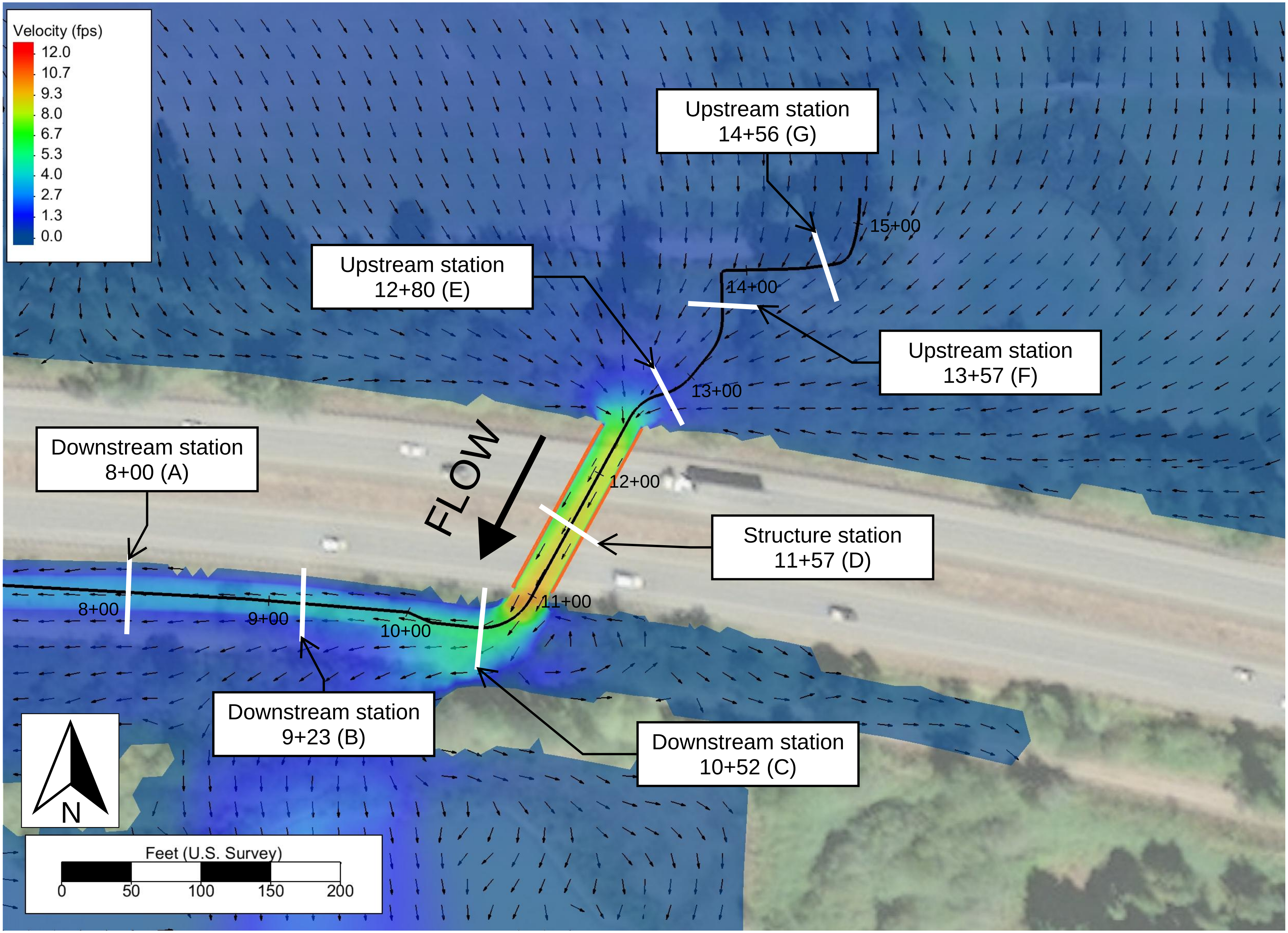

Figure H.34: Proposed conditions 500-year velocity

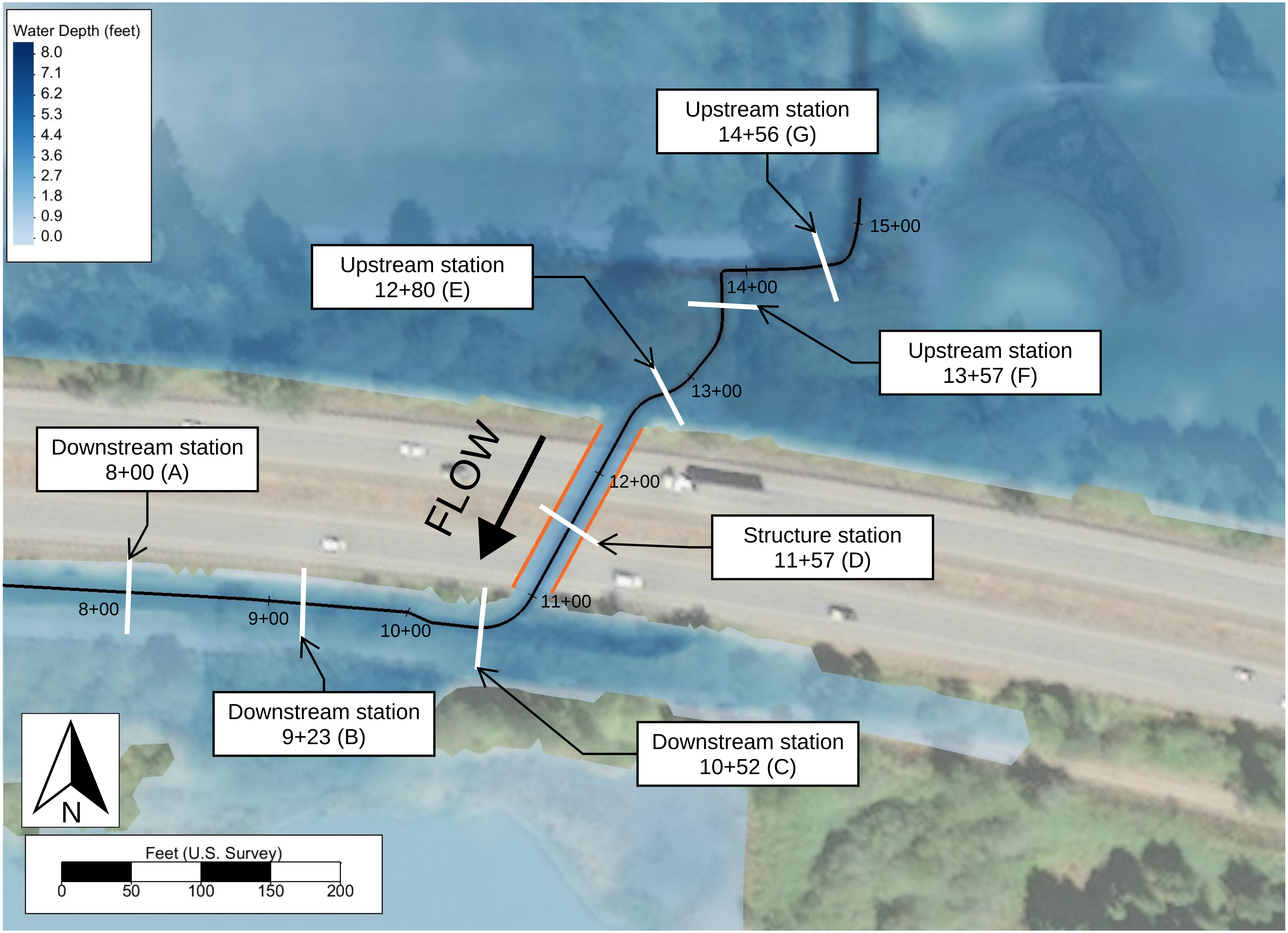

Figure H.35: Proposed conditions 500-year water depth

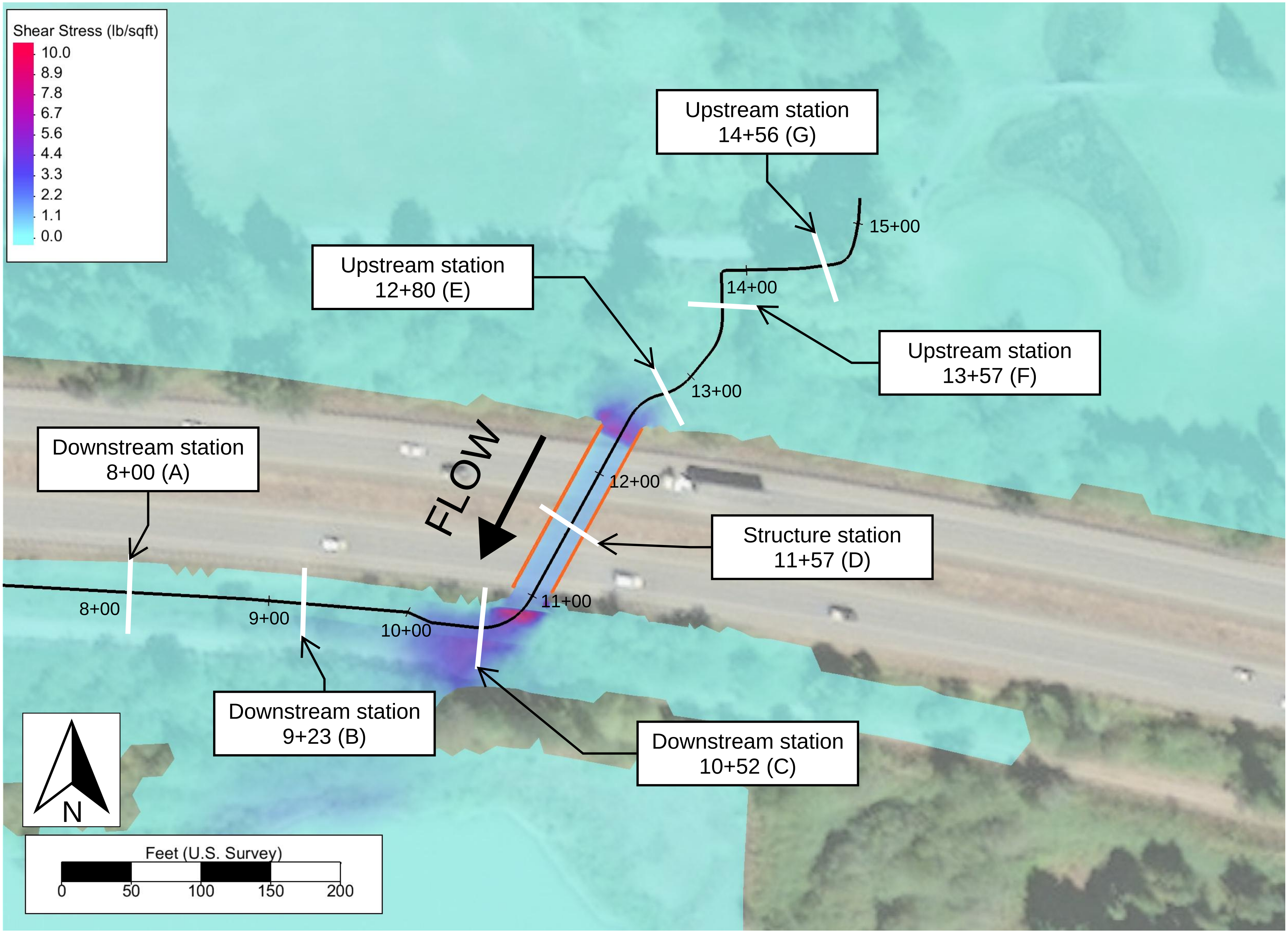

Figure H.36: Proposed conditions 500-year shear stress

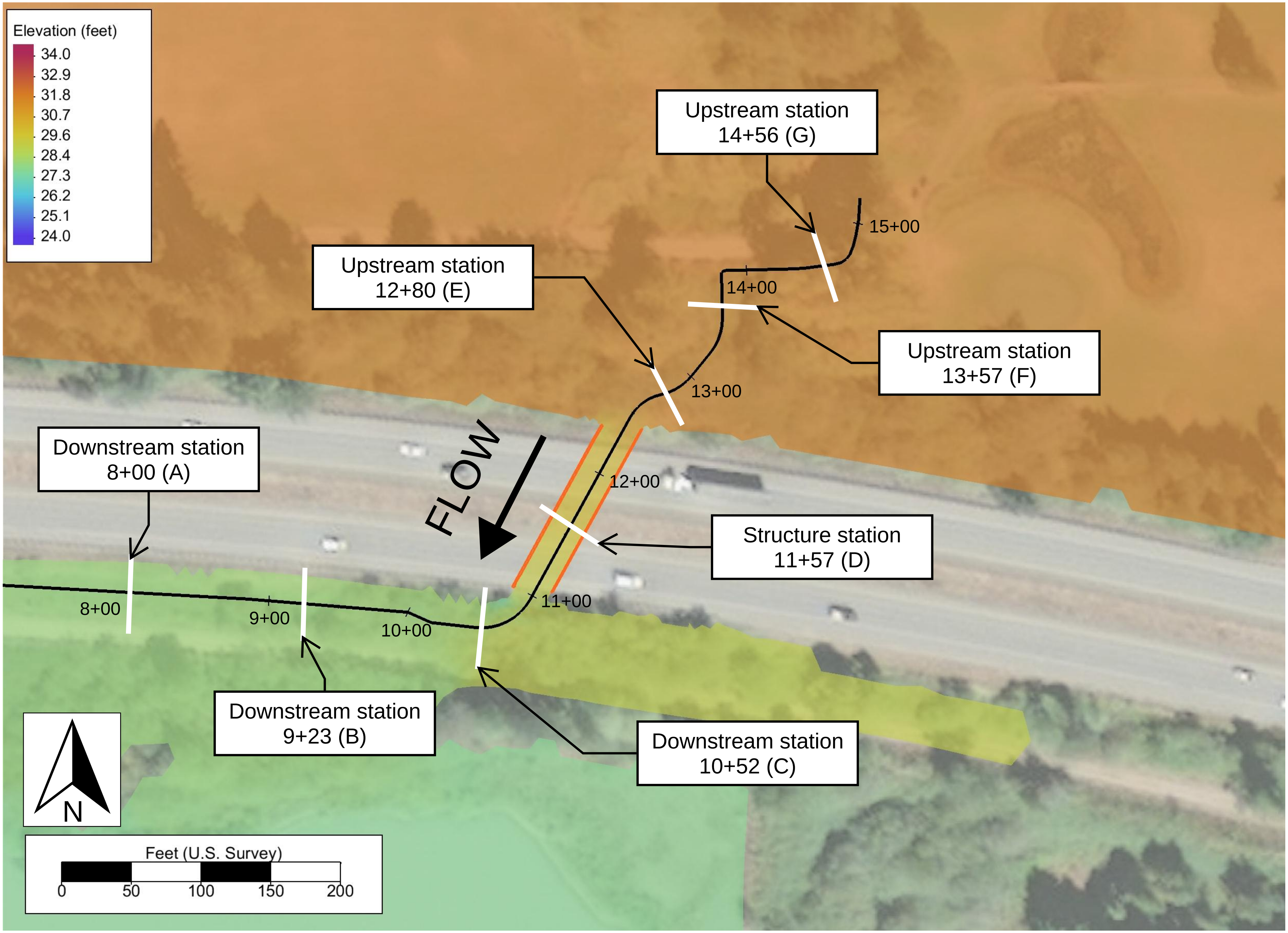

Figure H.37: Proposed conditions 2080 predicted 100-year water surface elevation

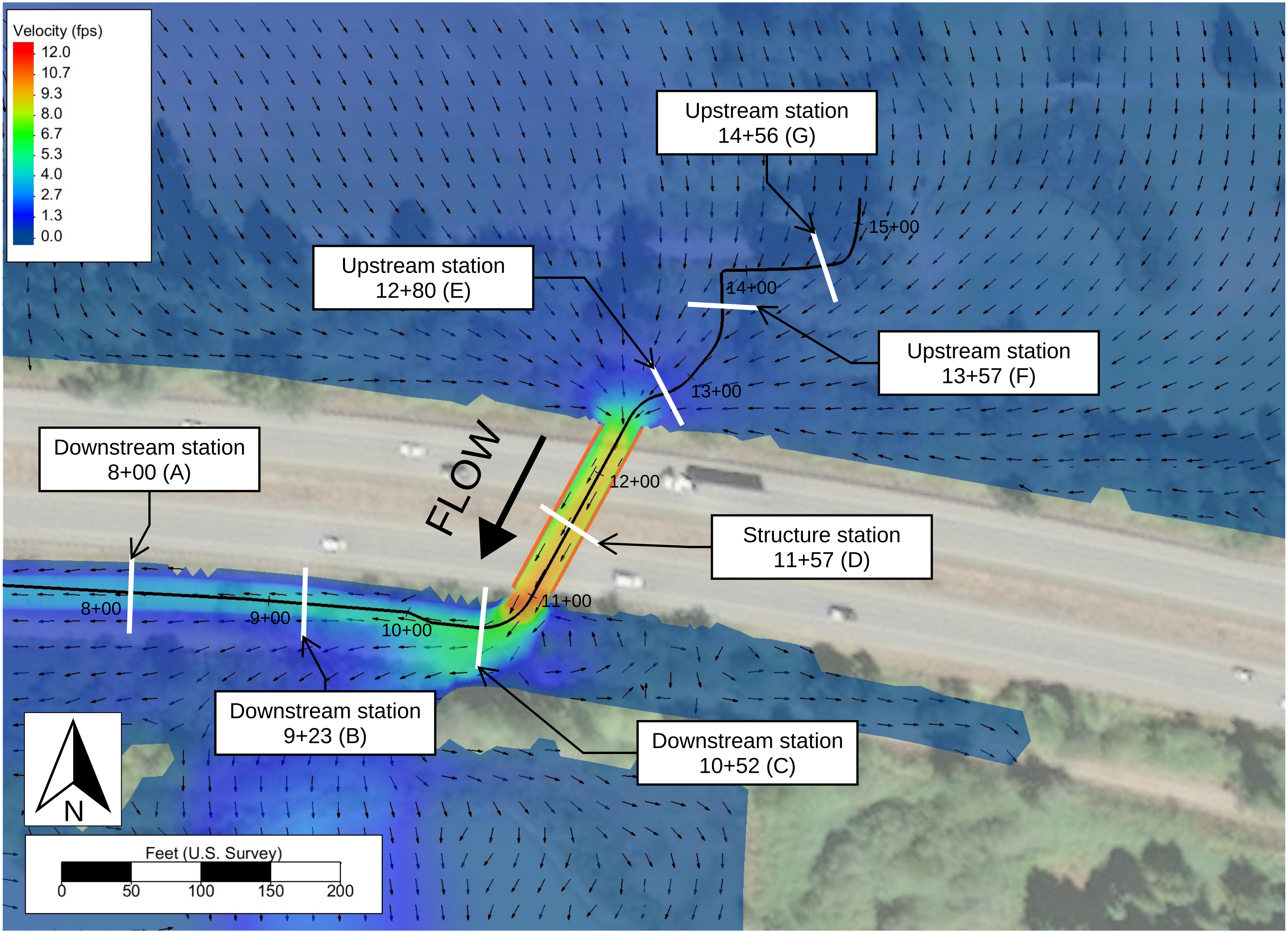

Figure H.38: Proposed conditions 2080 predicted 100-year velocity

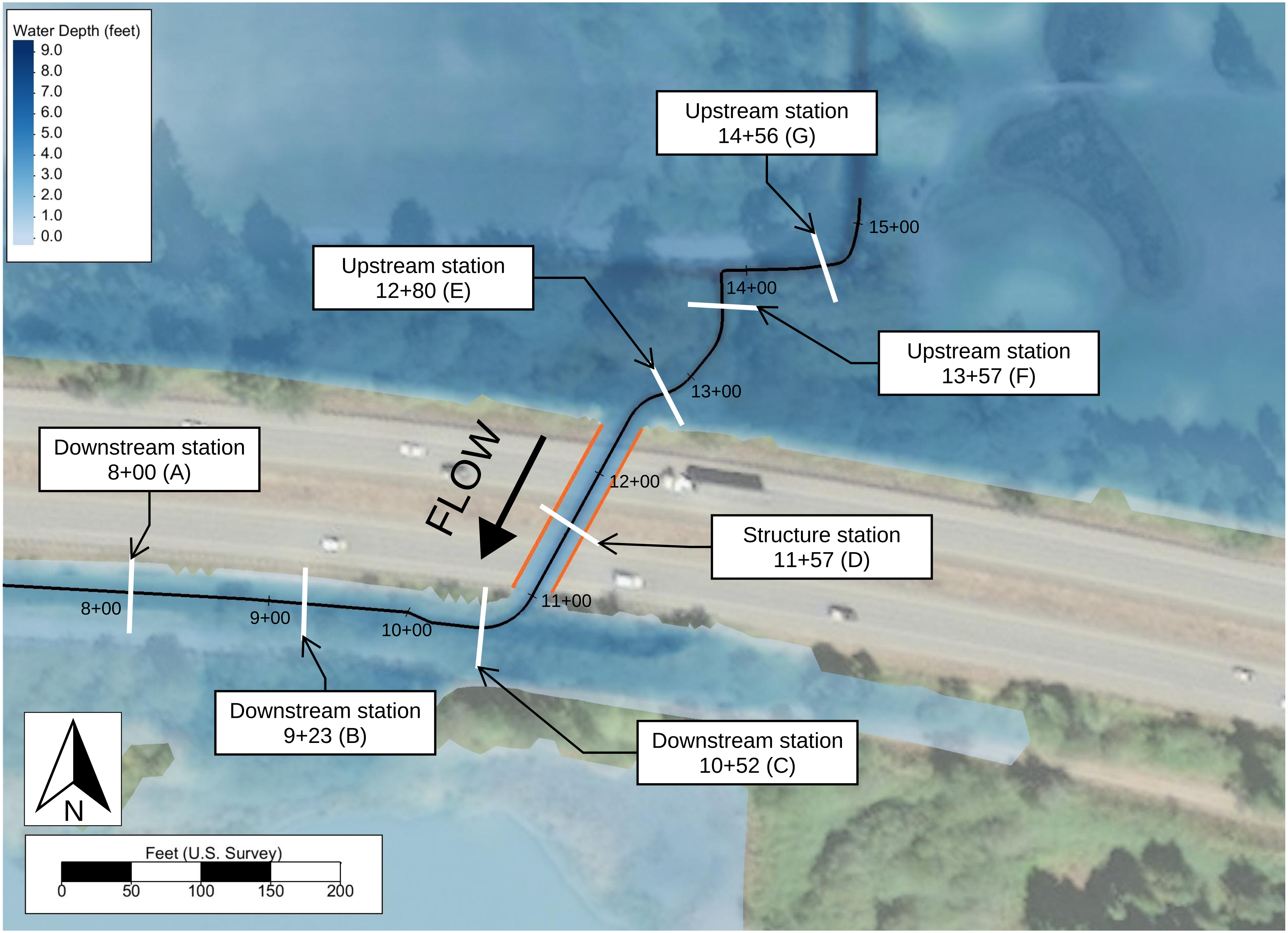

Figure H.39: Proposed conditions 2080 predicted 100-year water depth

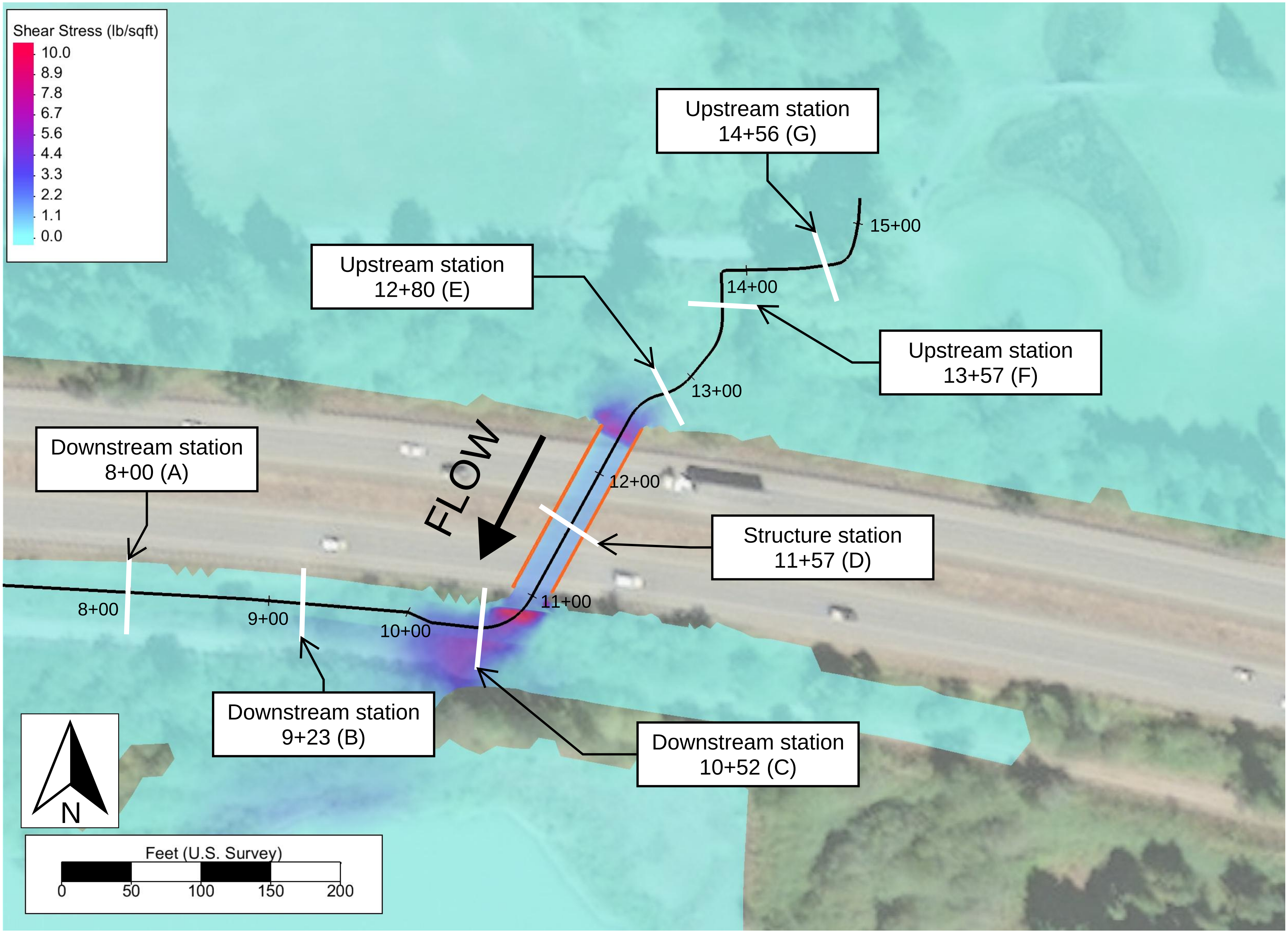

Figure H.40: Proposed conditions 2080 predicted 100-year shear stress

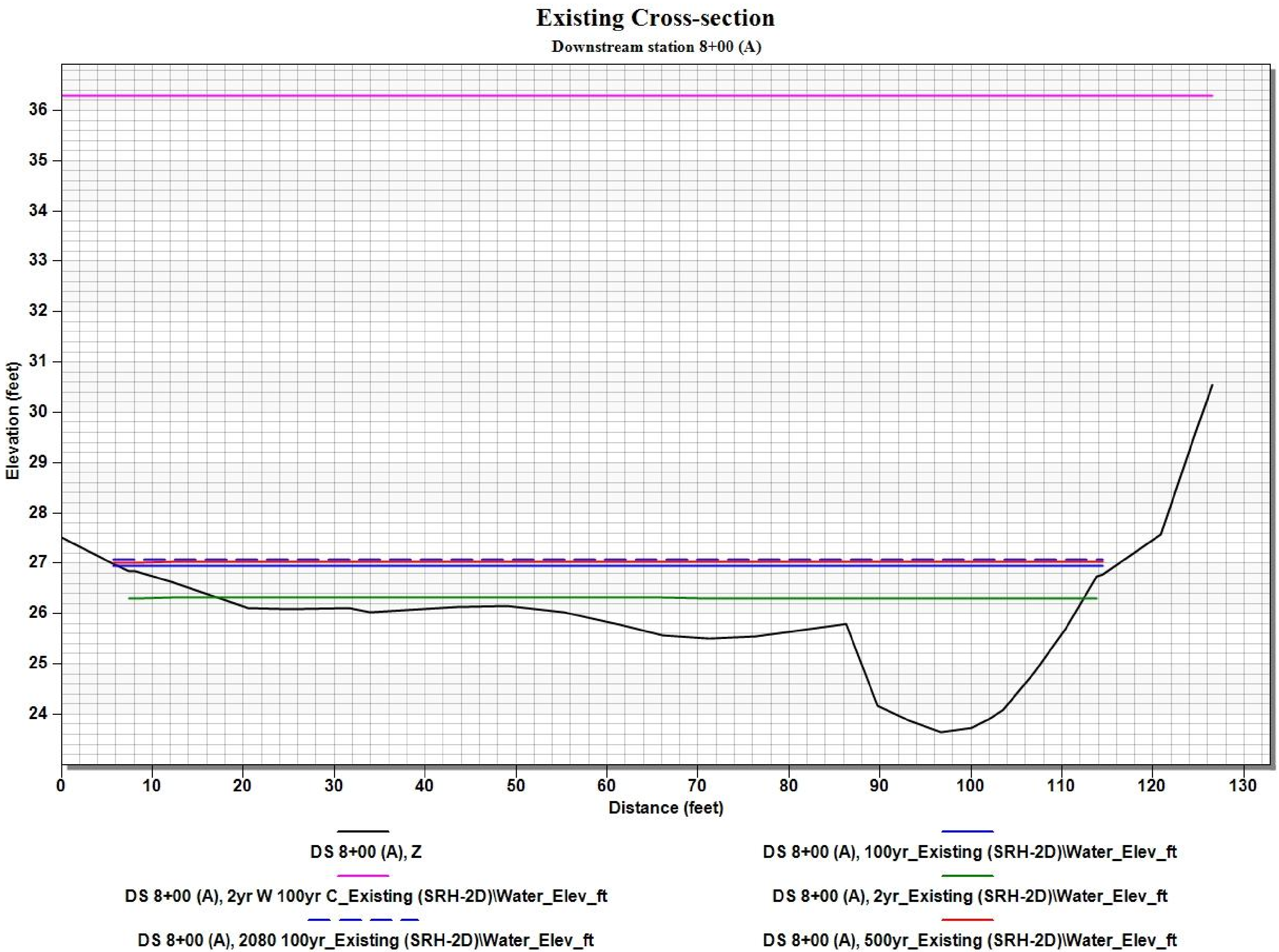

Figure H.41: Existing conditions cross-section at downstream station 8+00 (A)

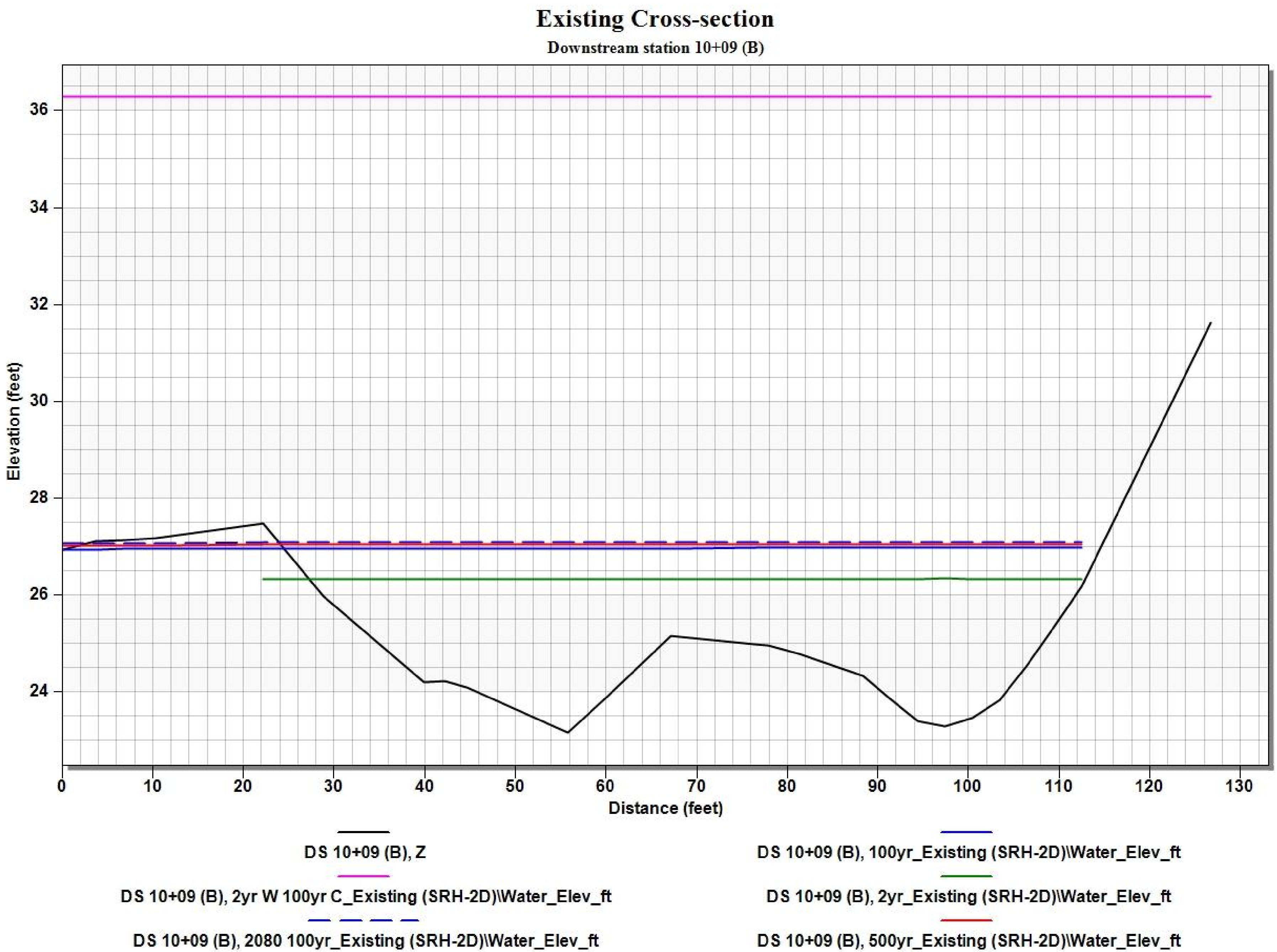

Figure H.42: Existing conditions cross-section at downstream station 10+09 (B)

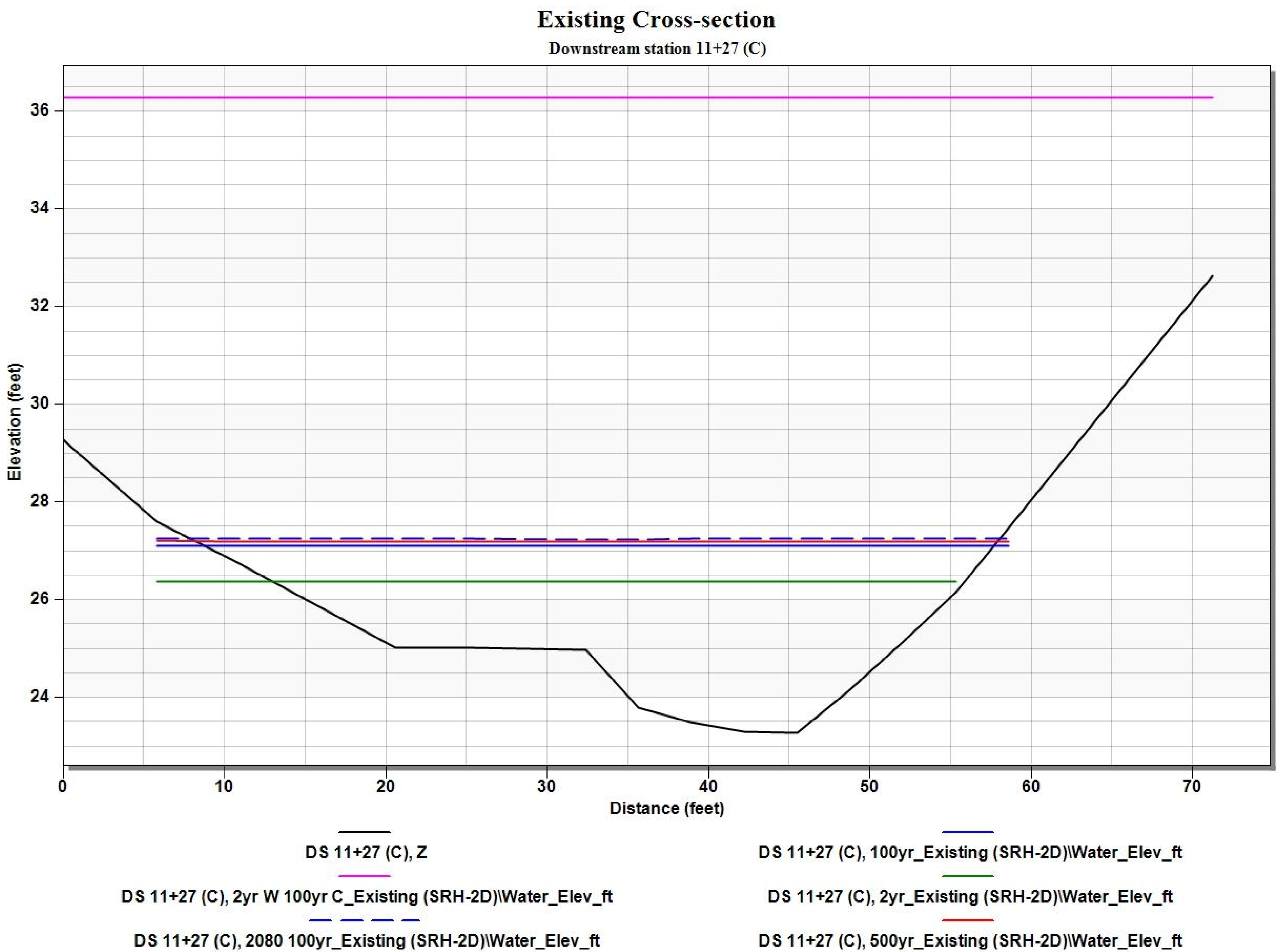

Figure H.43: Existing conditions cross-section at downstream station 11+27 (C)

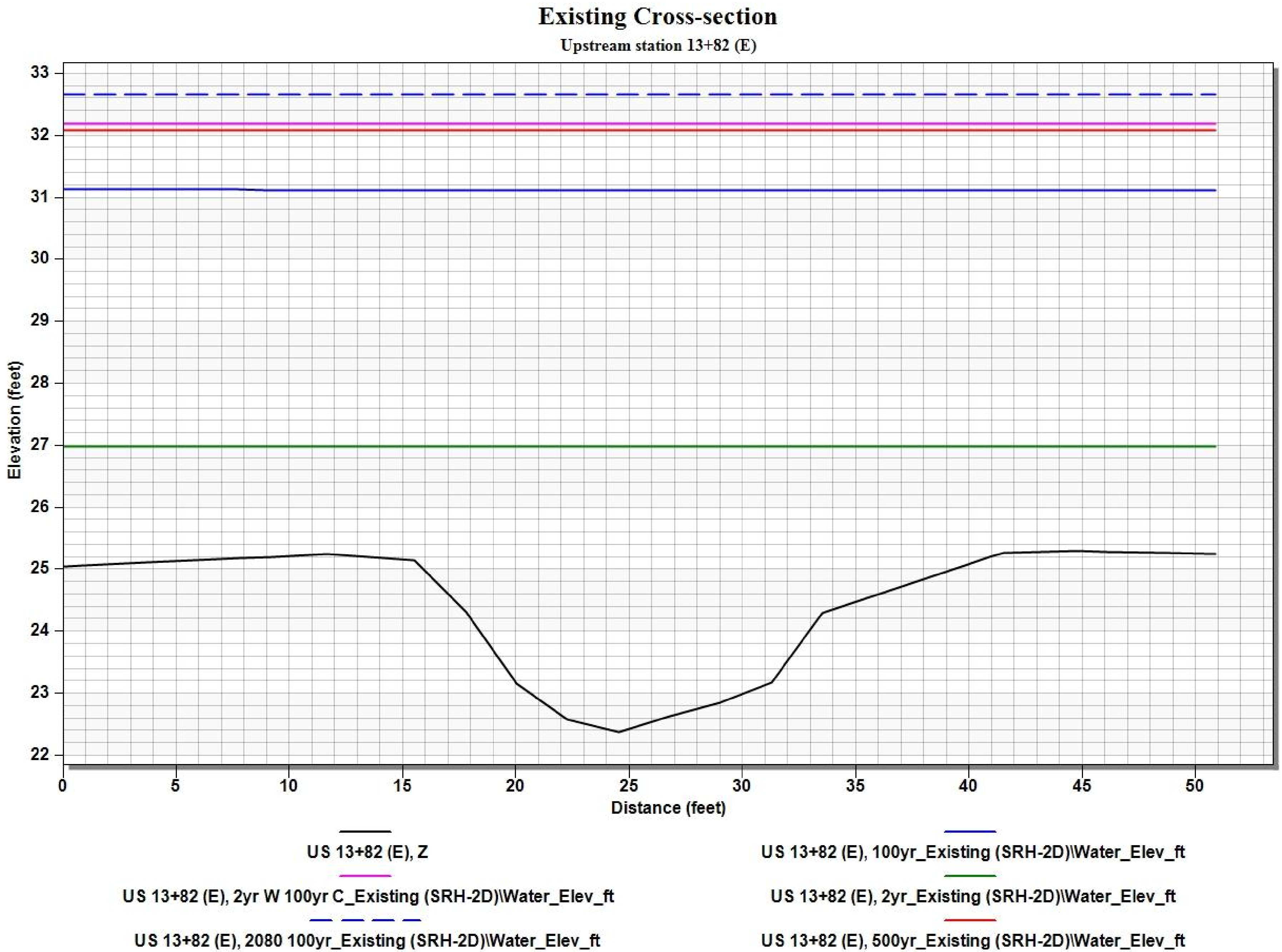

Figure H.44: Existing conditions cross-section at upstream station 13+82 (E)

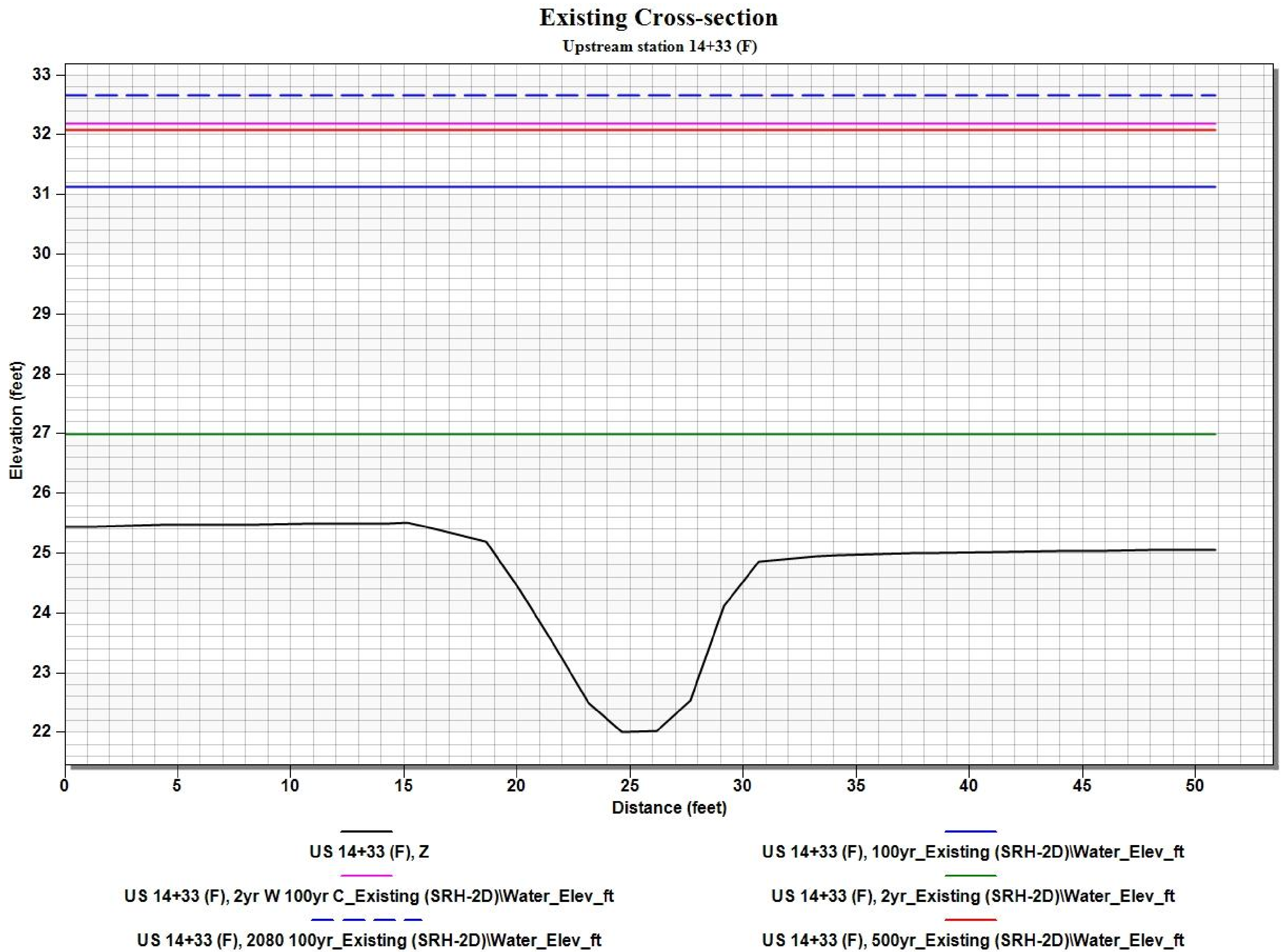

Figure H.45: Existing conditions cross-section at upstream station 14+33 (F)

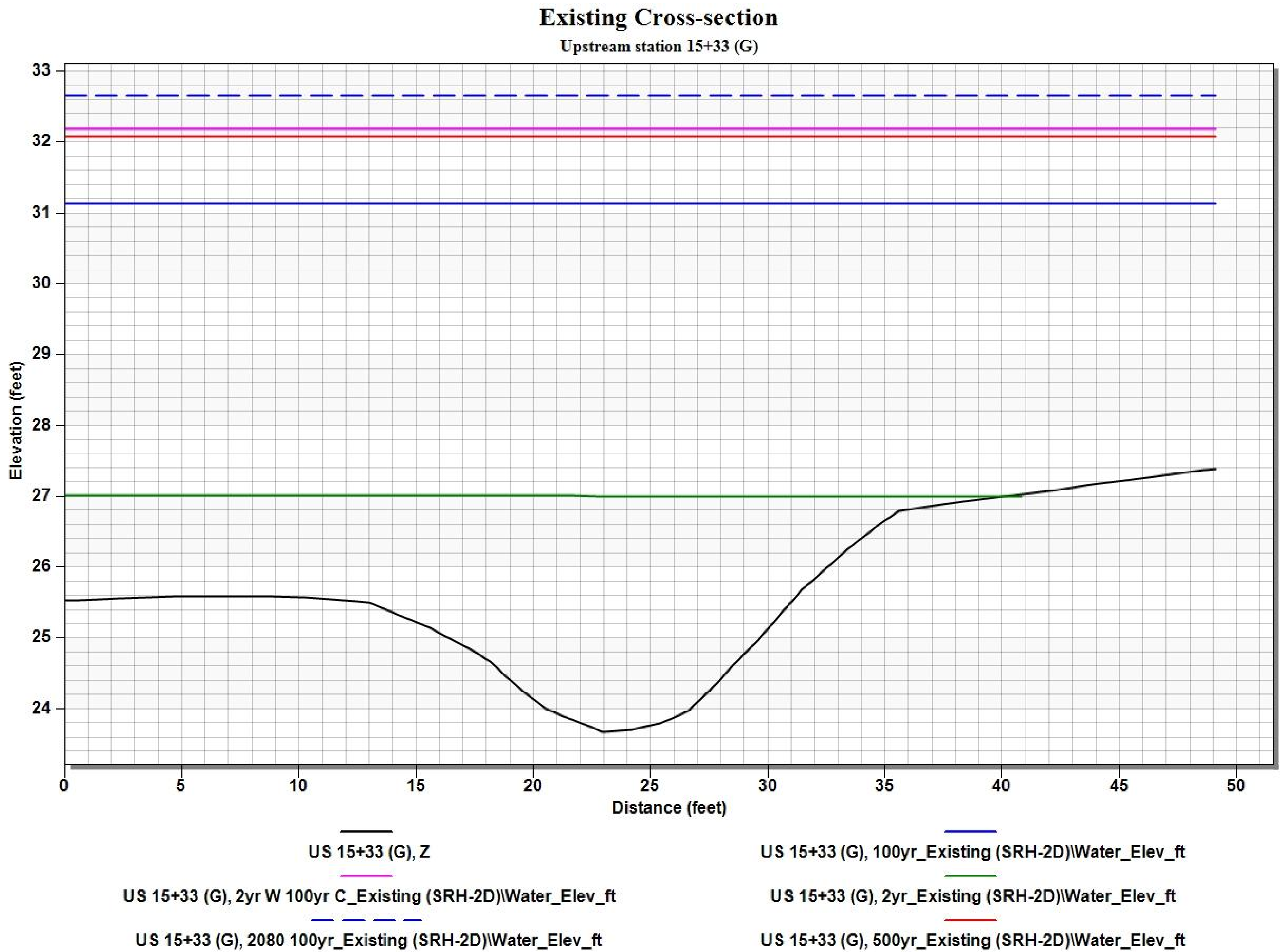

Figure H.46: Existing conditions cross-section at upstream station 15+33 (G)

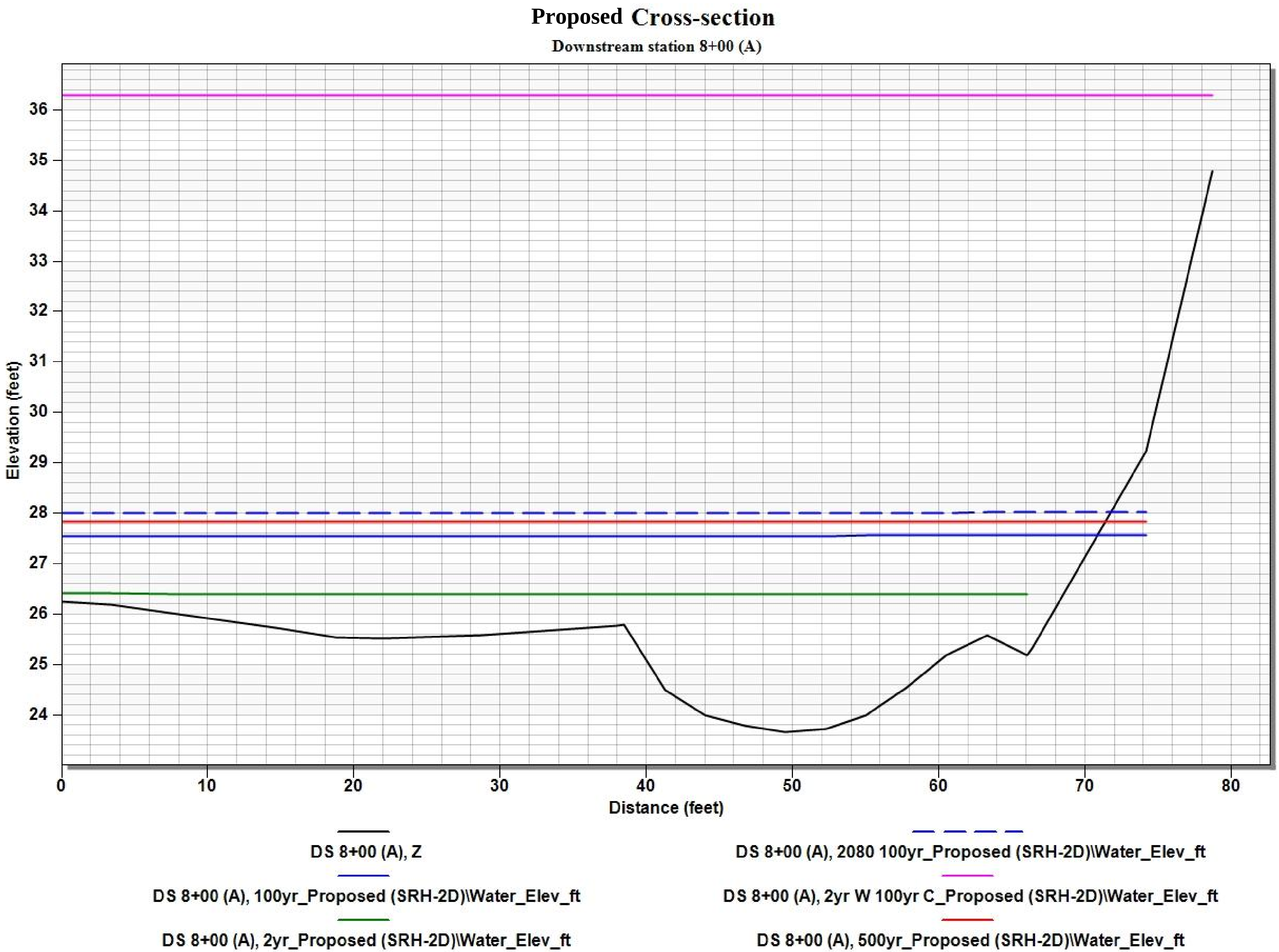

Figure H.47: Proposed conditions cross-section at downstream station 8+00 (A)

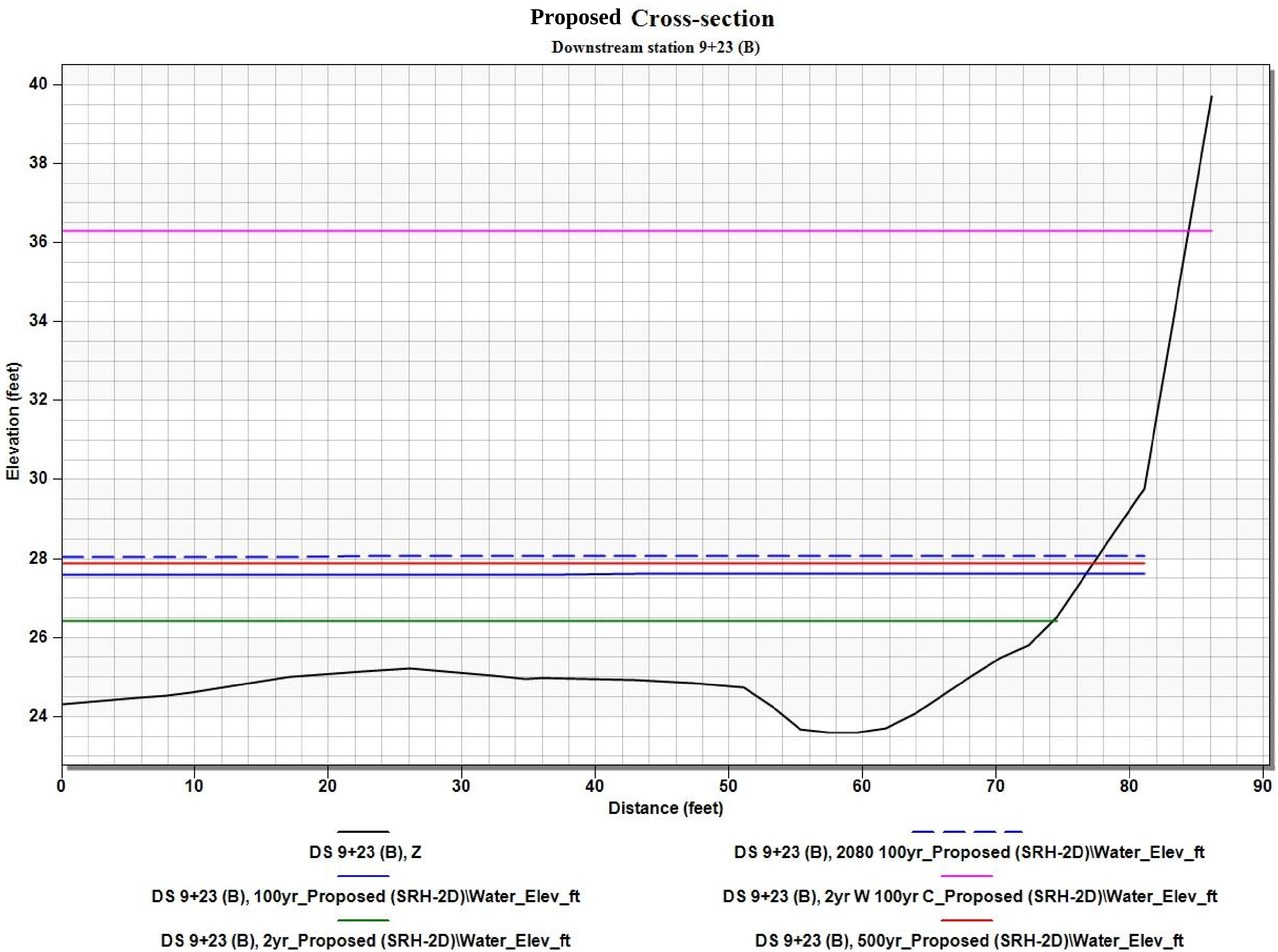

Figure H.48: Proposed conditions cross-section at downstream station 9+23 (B)

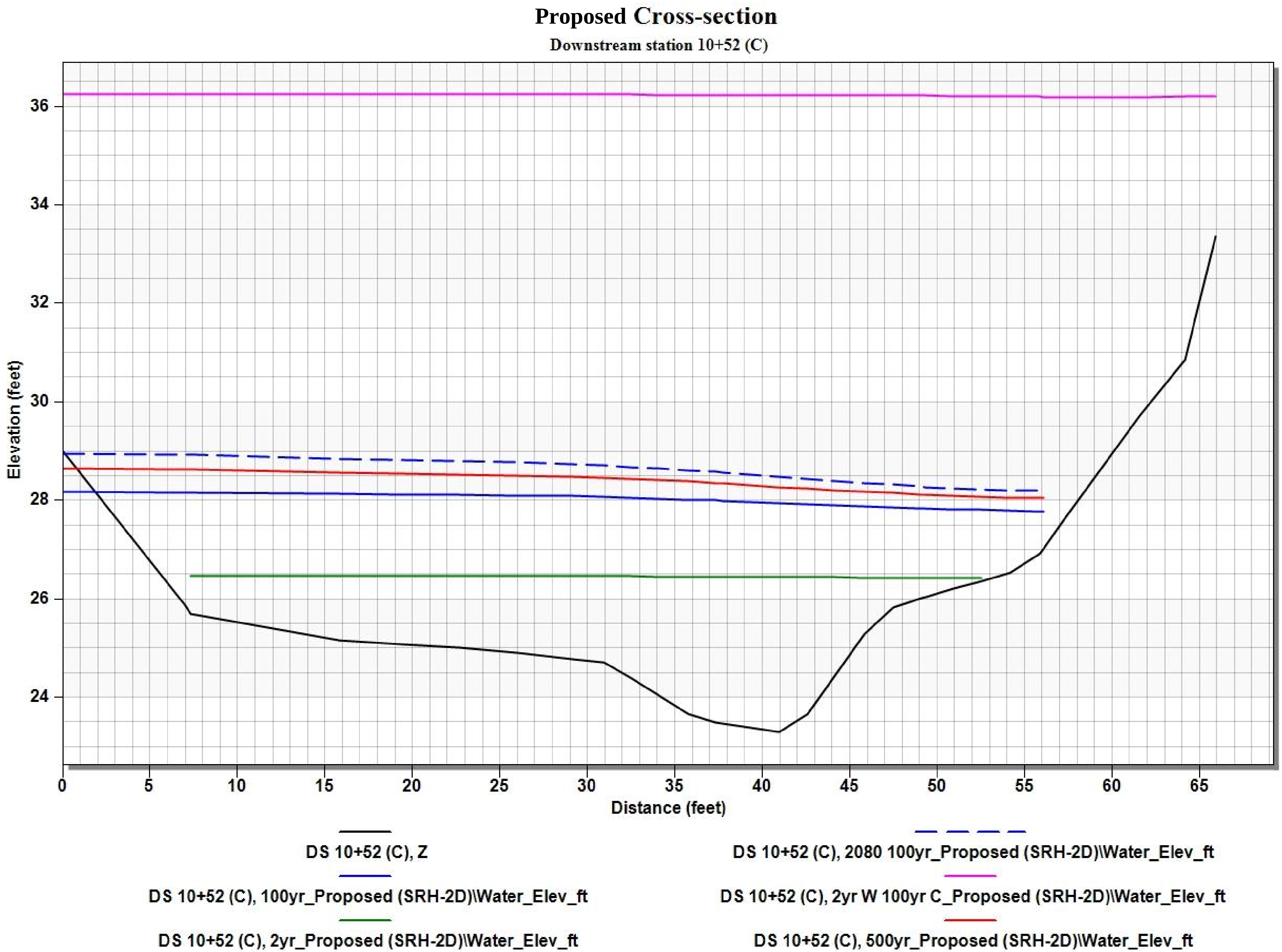

Figure H.49: Proposed conditions cross-section at downstream station 10+52 (C)

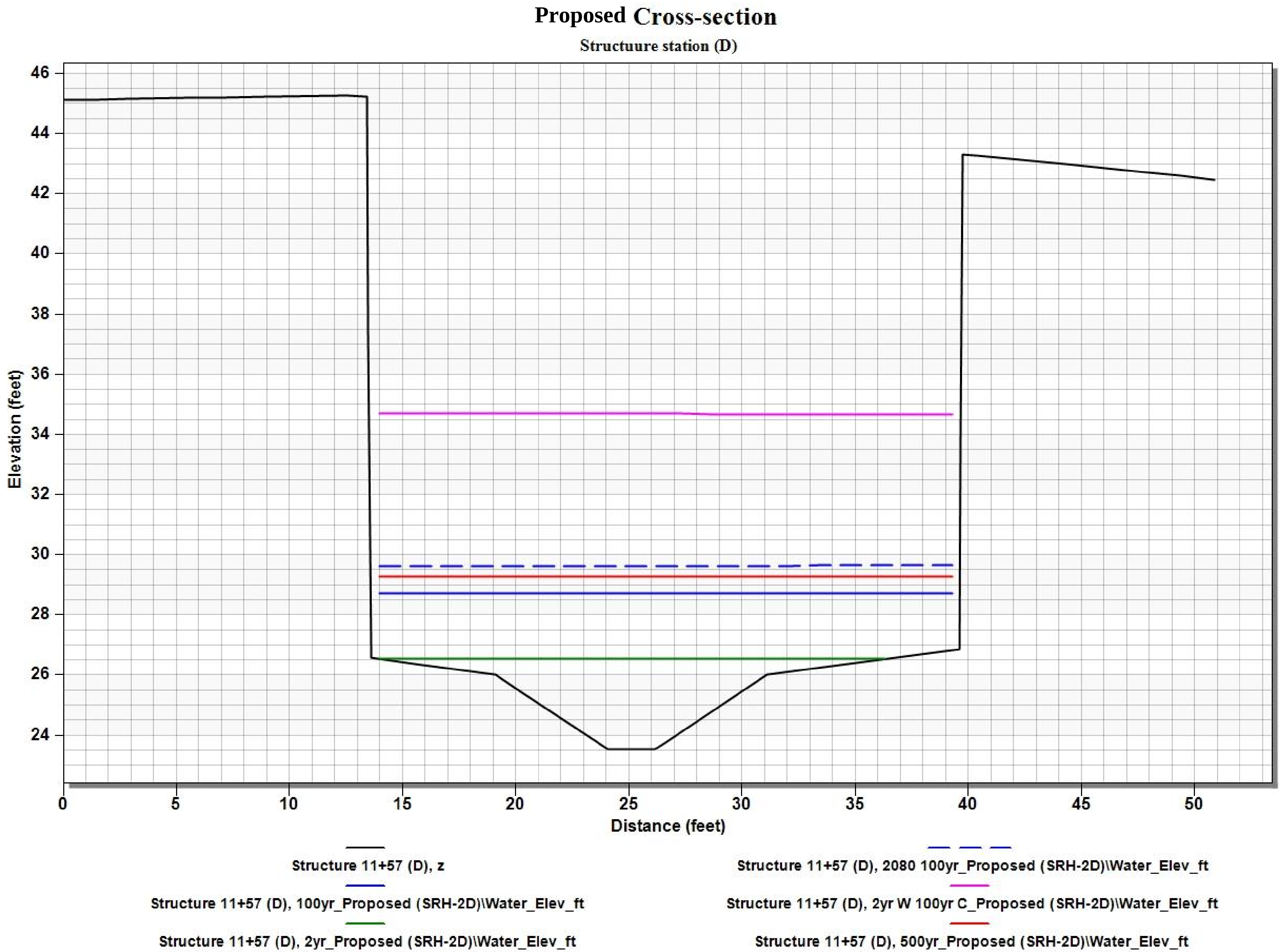

Figure H.50: Proposed conditions cross-section at the structure 11+57 (D)

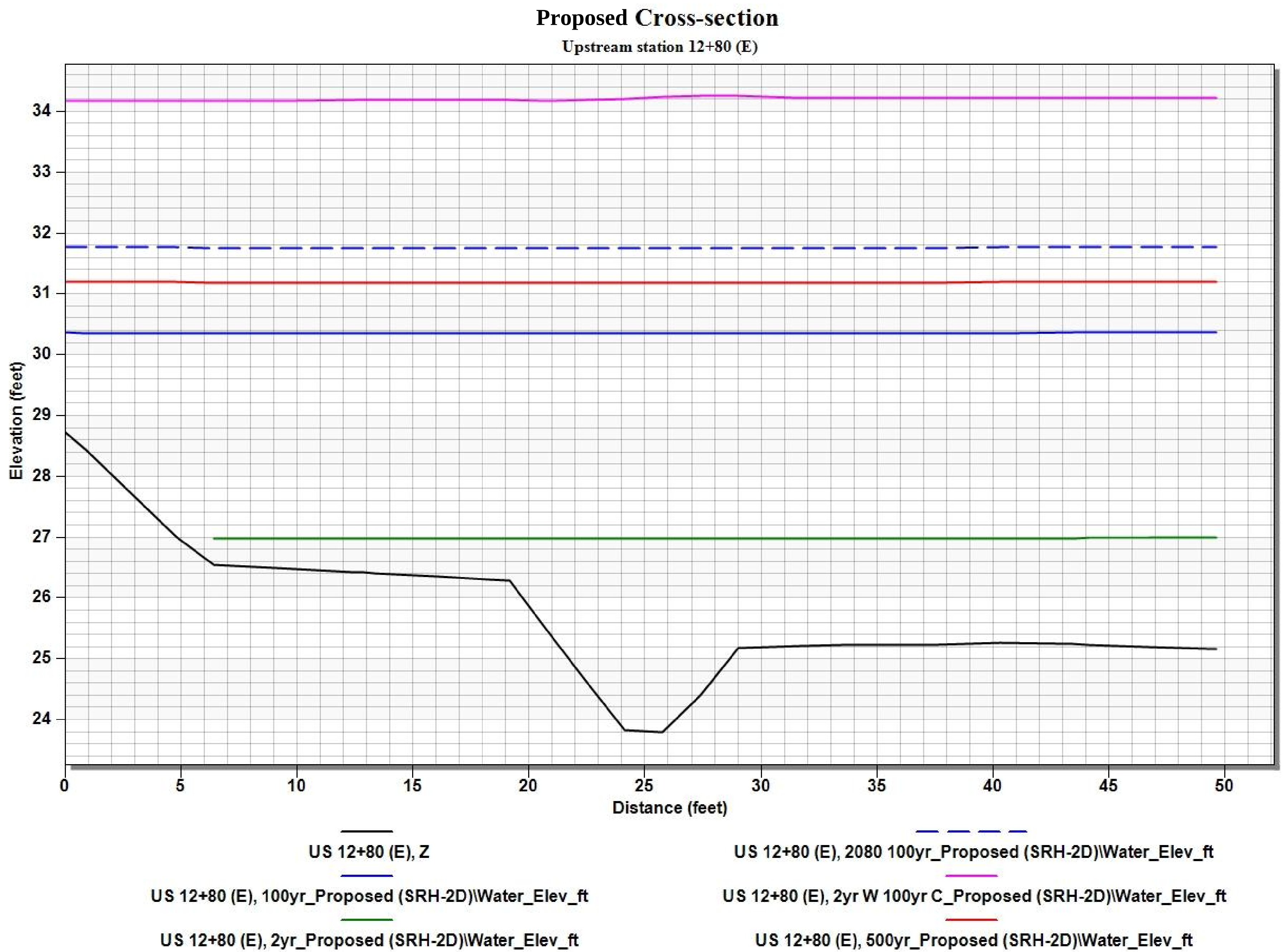

Figure H.51: Proposed conditions cross-section at upstream station 12+80 (E)

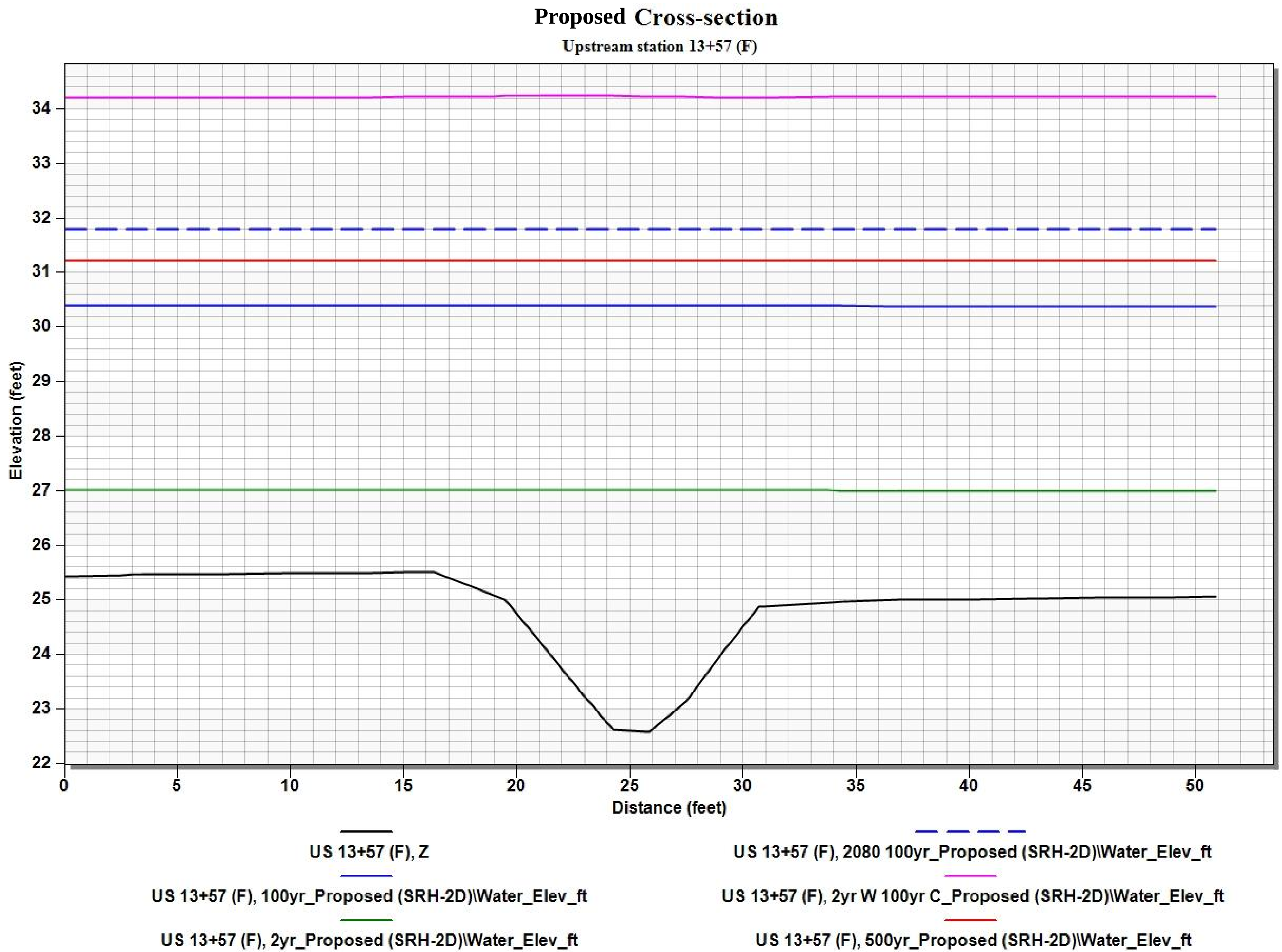

Figure H.52: Proposed conditions cross-section at upstream station 13+57 (F)

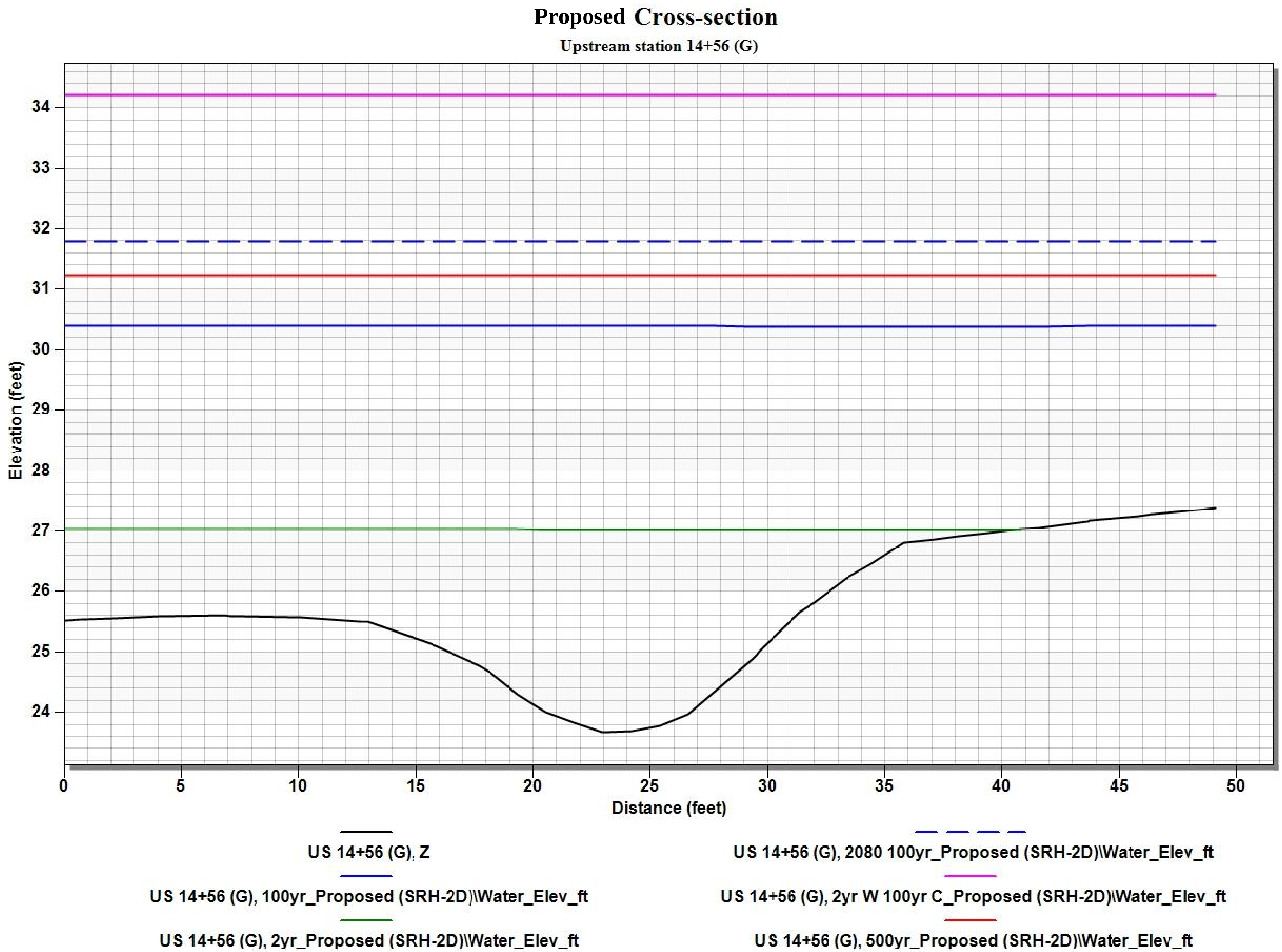

Figure H.53: Proposed conditions cross-section at upstream station 14+56 (G)

Appendix I: SRH-2D Model Stability and Continuity

Figure I1: Existing conditions monitor line locations

Figure I2: Existing conditions monitor point locations

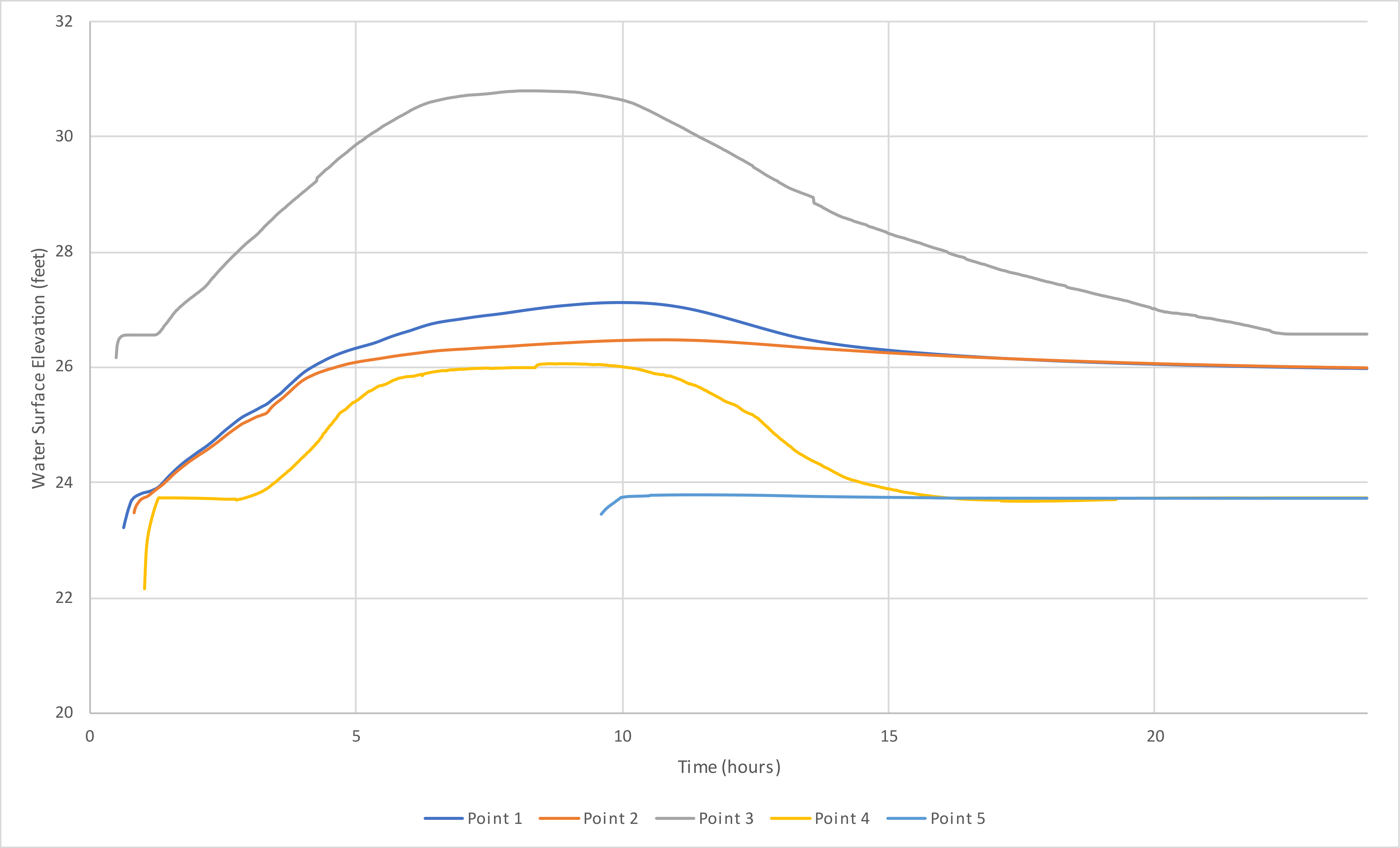

Figure I3: Existing-conditions 2-year UNT to Wenzel monitor points

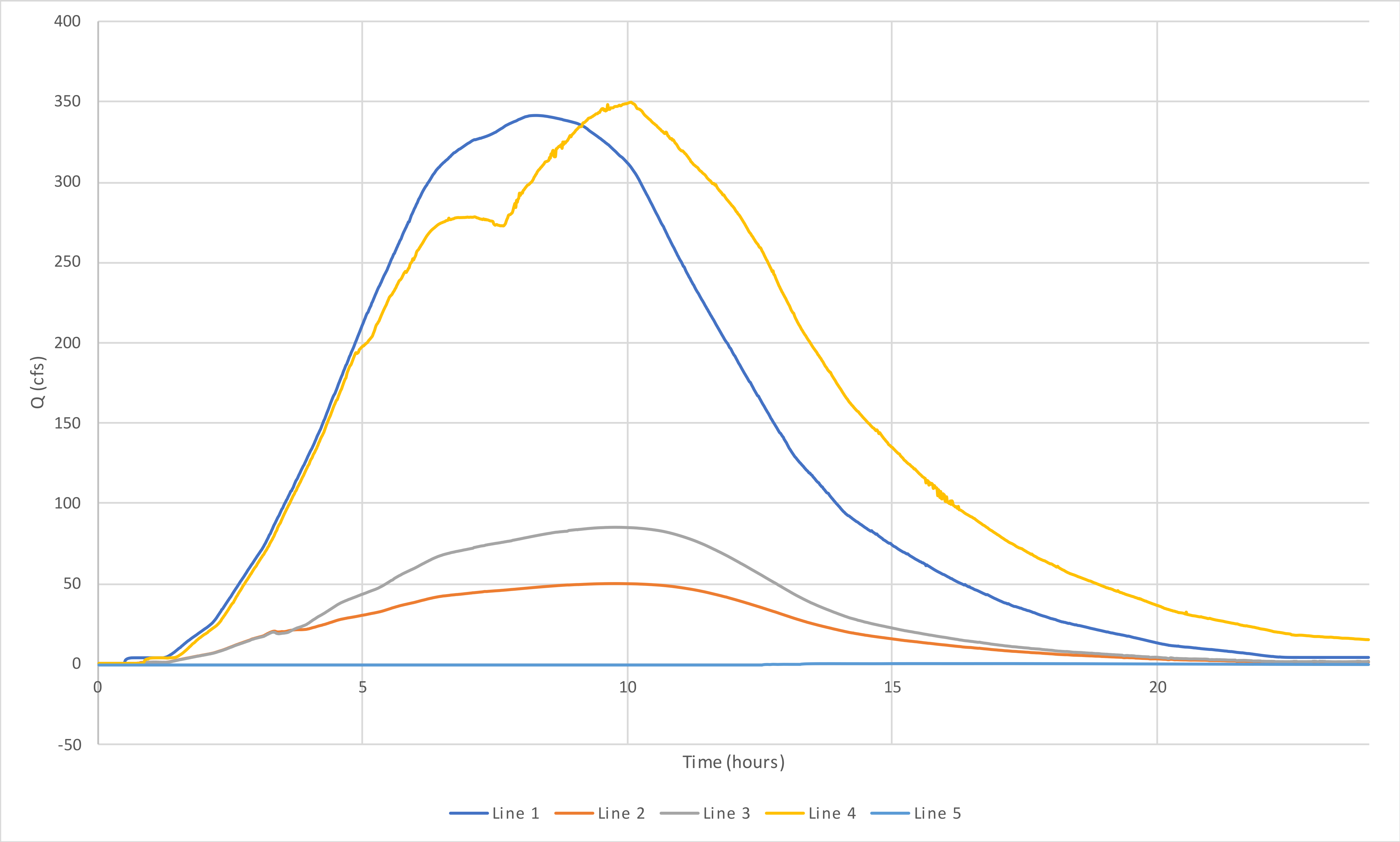

Figure I4: Existing-conditions 2-year UNT to Wenzel monitor lines

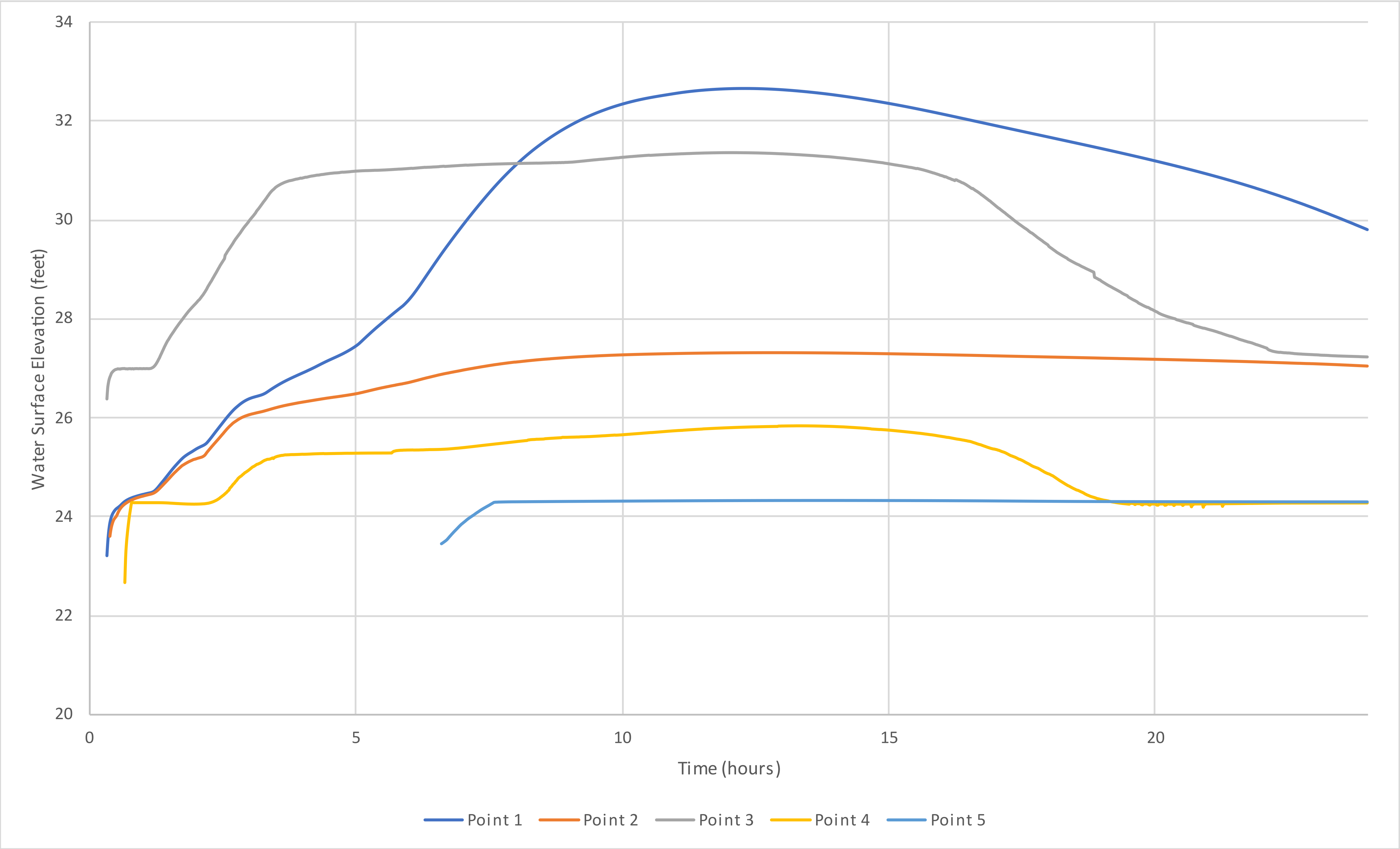

Figure I5: Existing-conditions 100-year UNT to Wenzel monitor points

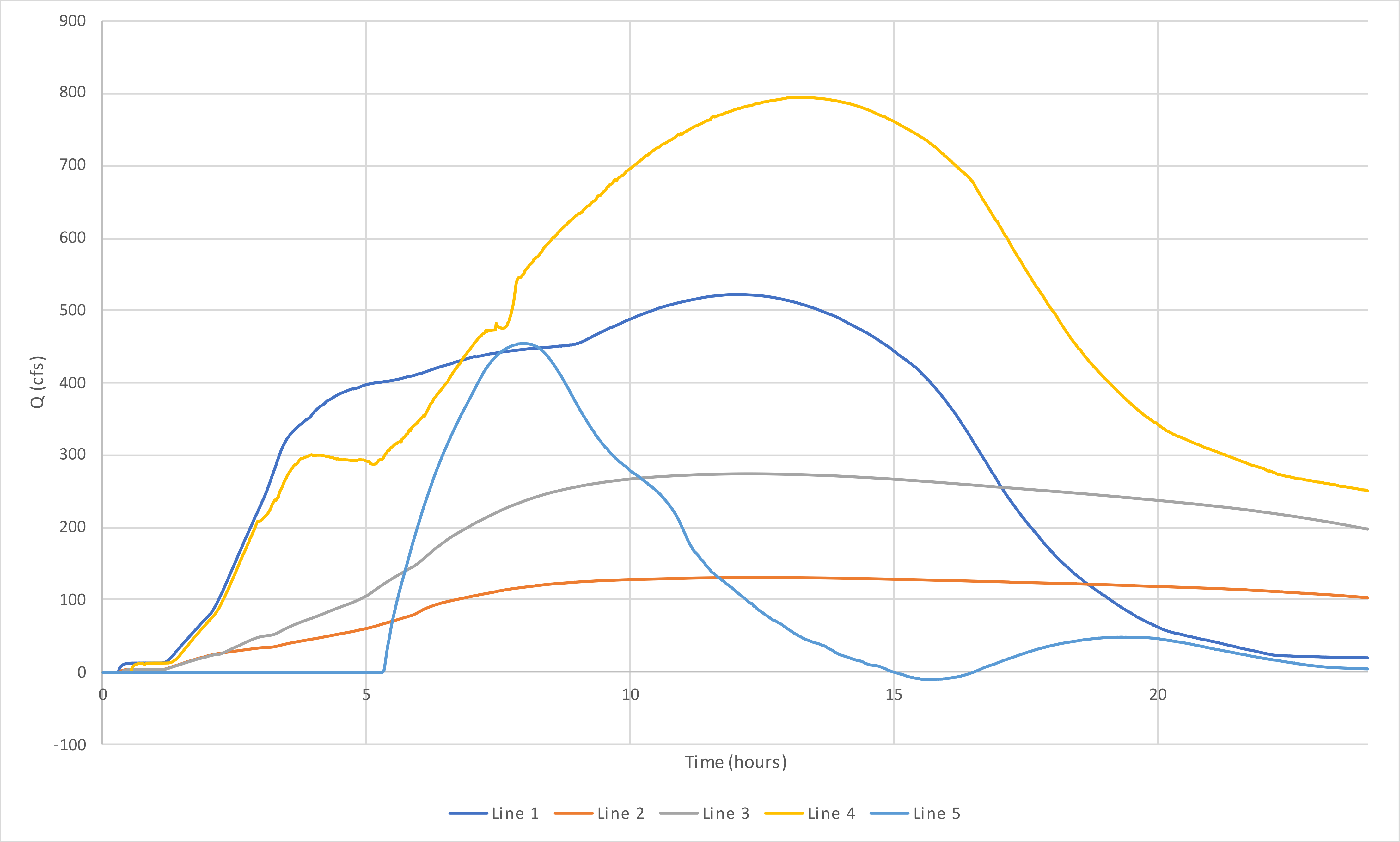

Figure I6: Existing-conditions 100-year UNT to Wenzel monitor lines

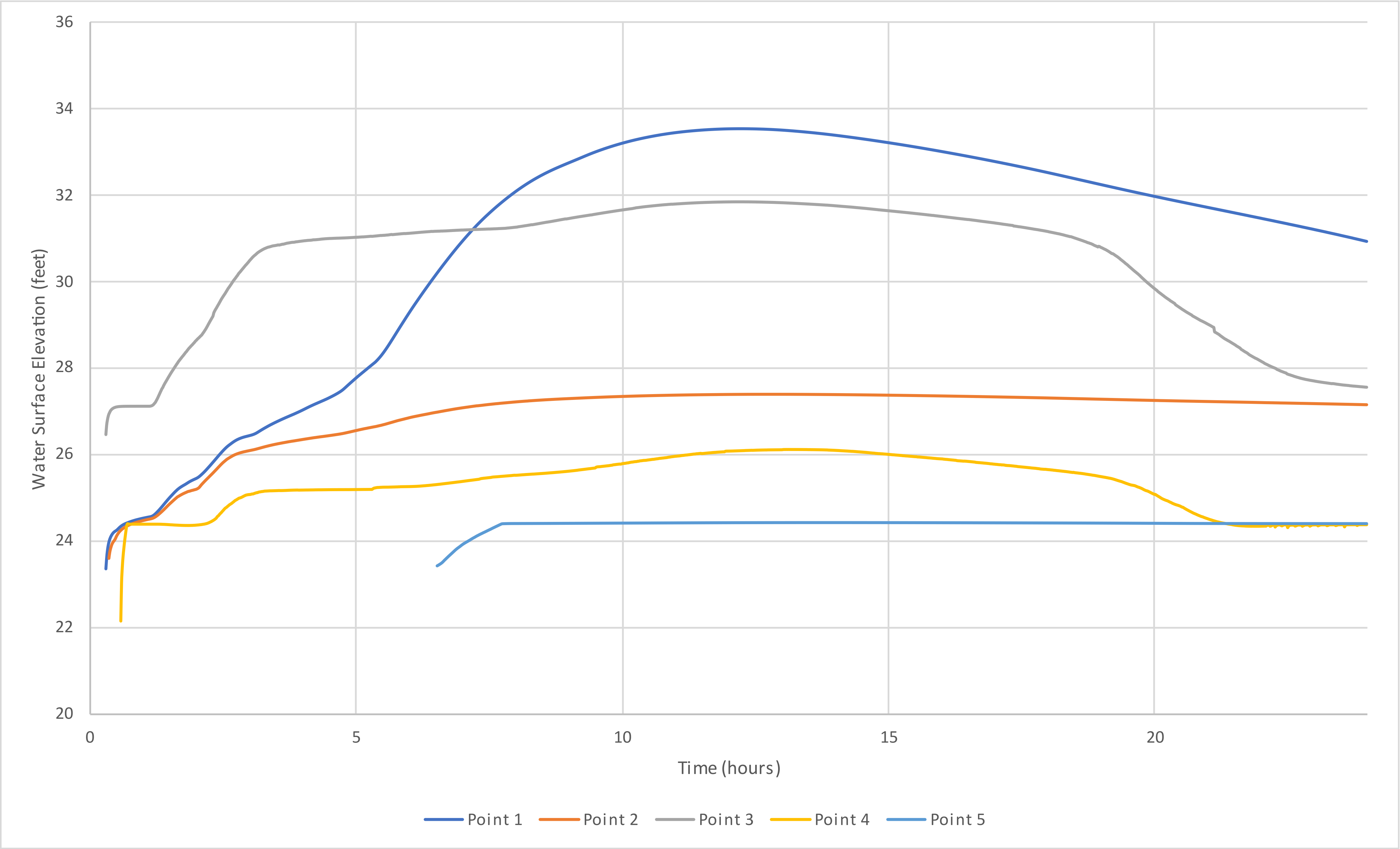

Figure I7: Existing-conditions 500-year UNT to Wenzel monitor points

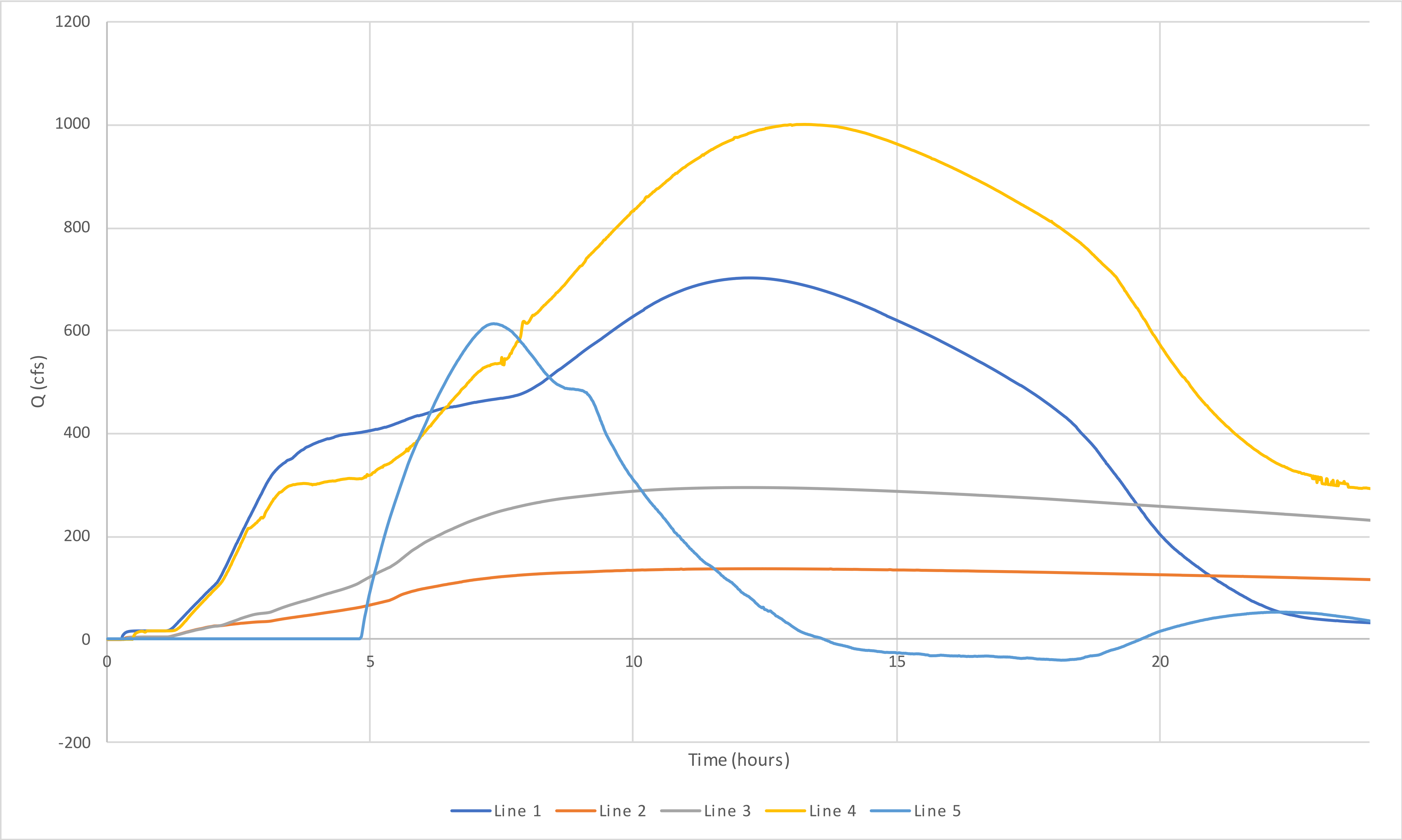

Figure I8: Existing-conditions 500-year UNT to Wenzel monitor lines

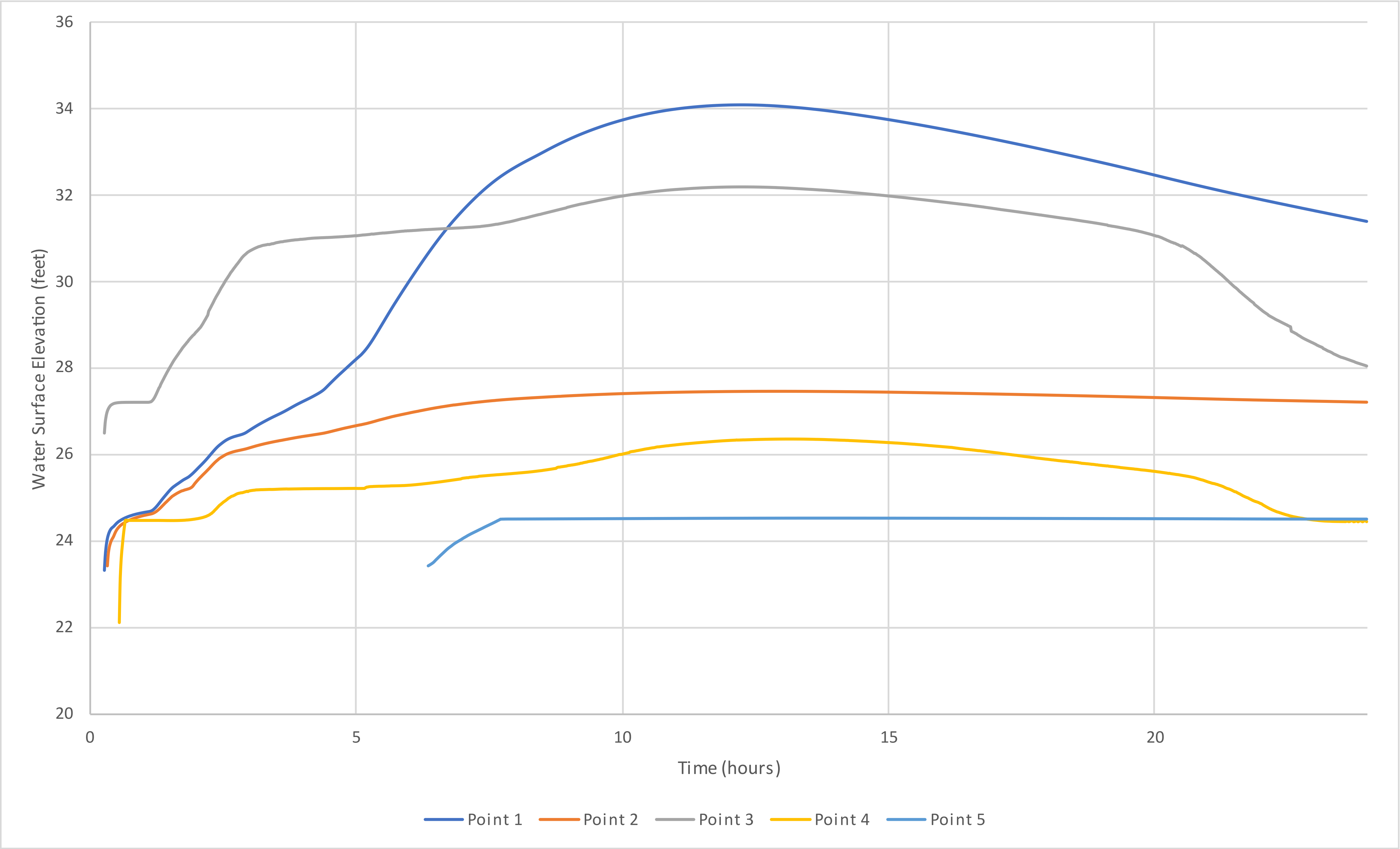

Figure I9: Existing-conditions 2080 projected 100-year UNT to Wenzel monitor points

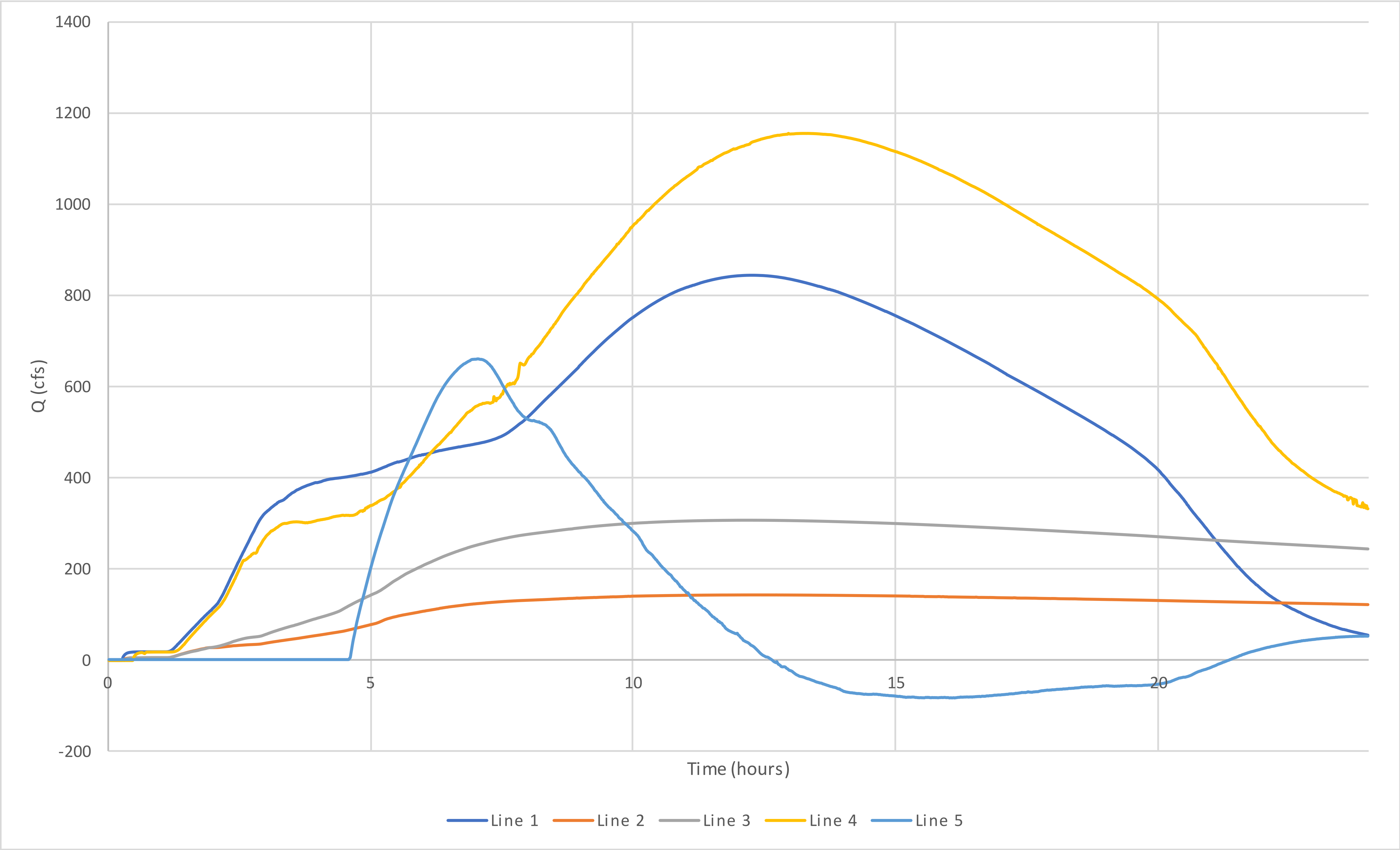

Figure I10: Existing-conditions 2080 projected 100-year UNT to Wenzel monitor lines

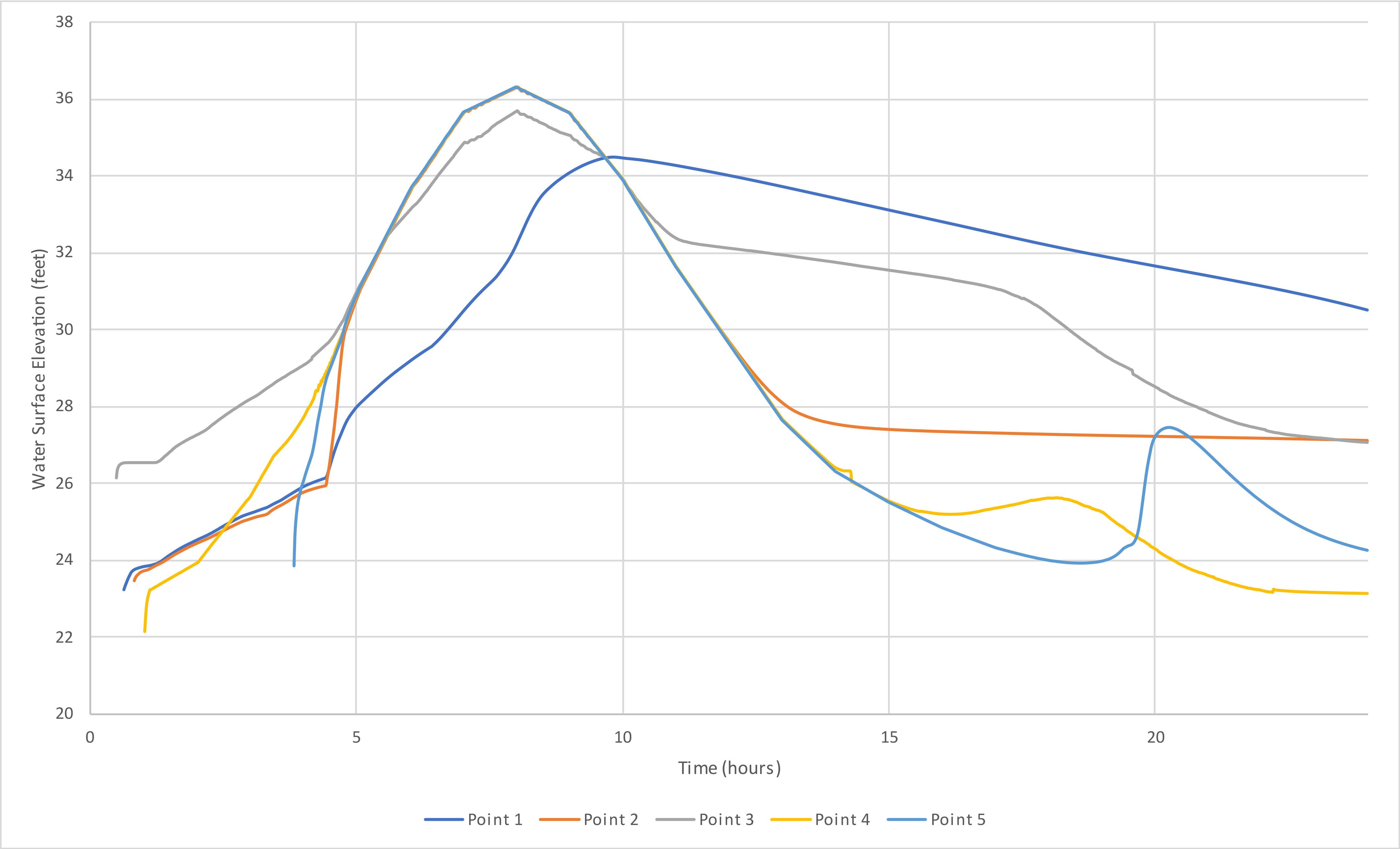

Figure I11: Existing-conditions 2-year UNT to Wenzel 100-year Chehalis River monitor points

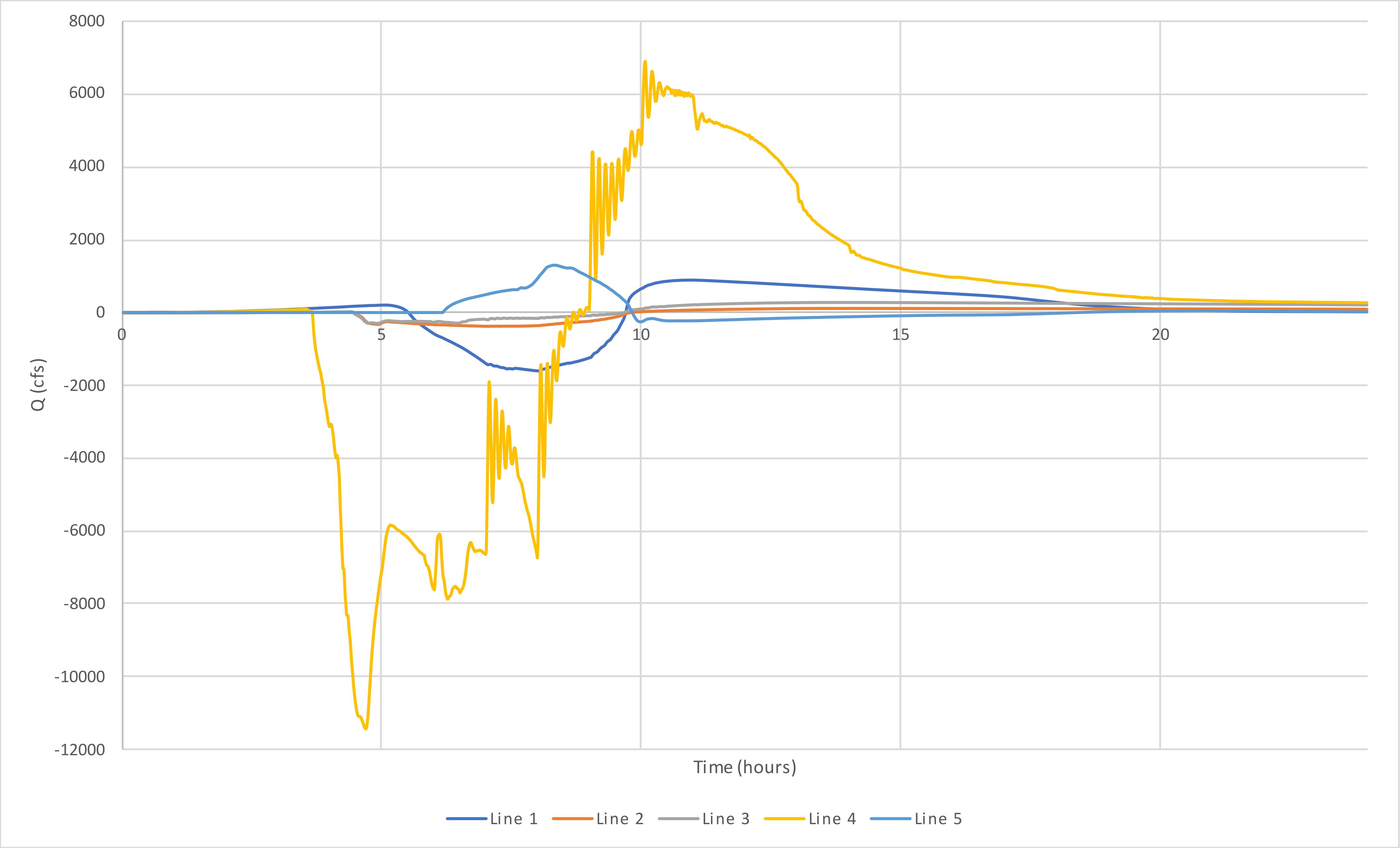

Figure I12: Existing-conditions 2-year UNT to Wenzel 100-year Chehalis River monitor lines

Figure I13: Proposed conditions monitor line locations

Figure I14: Proposed conditions monitor point locations

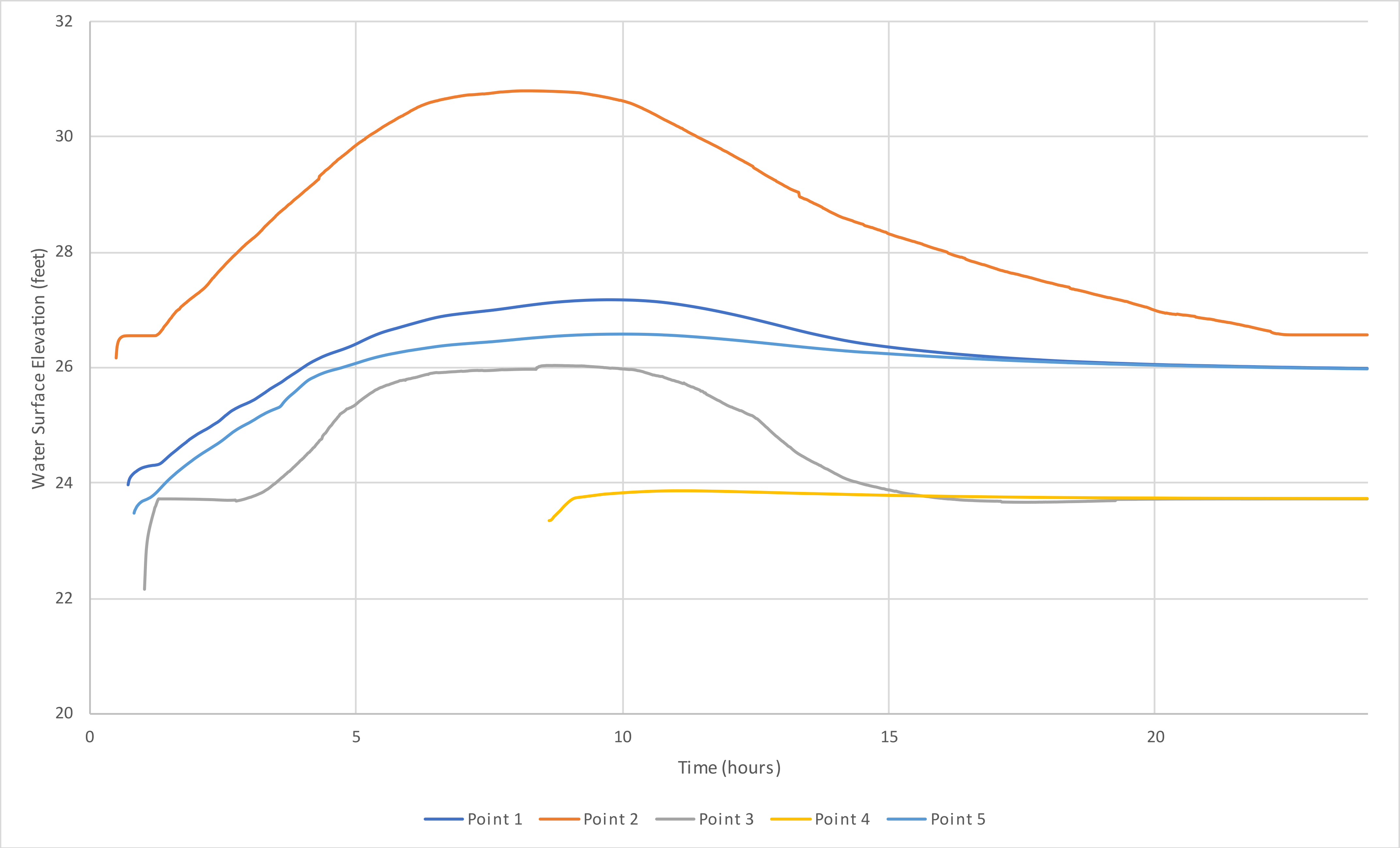

Figure I15: Proposed-conditions 2-year UNT to Wenzel monitor points

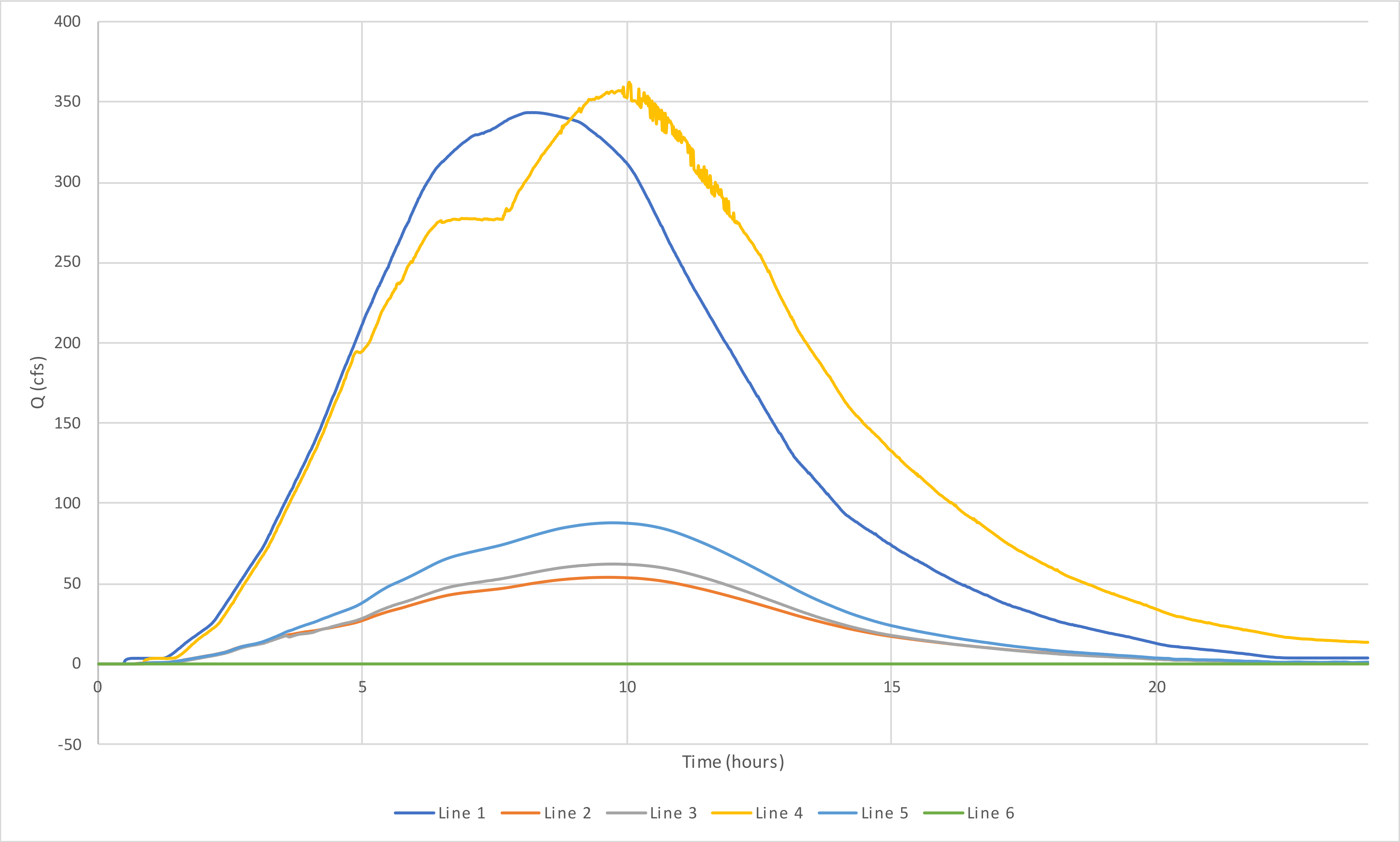

Figure I16: Proposed-conditions 2-year UNT to Wenzel monitor lines

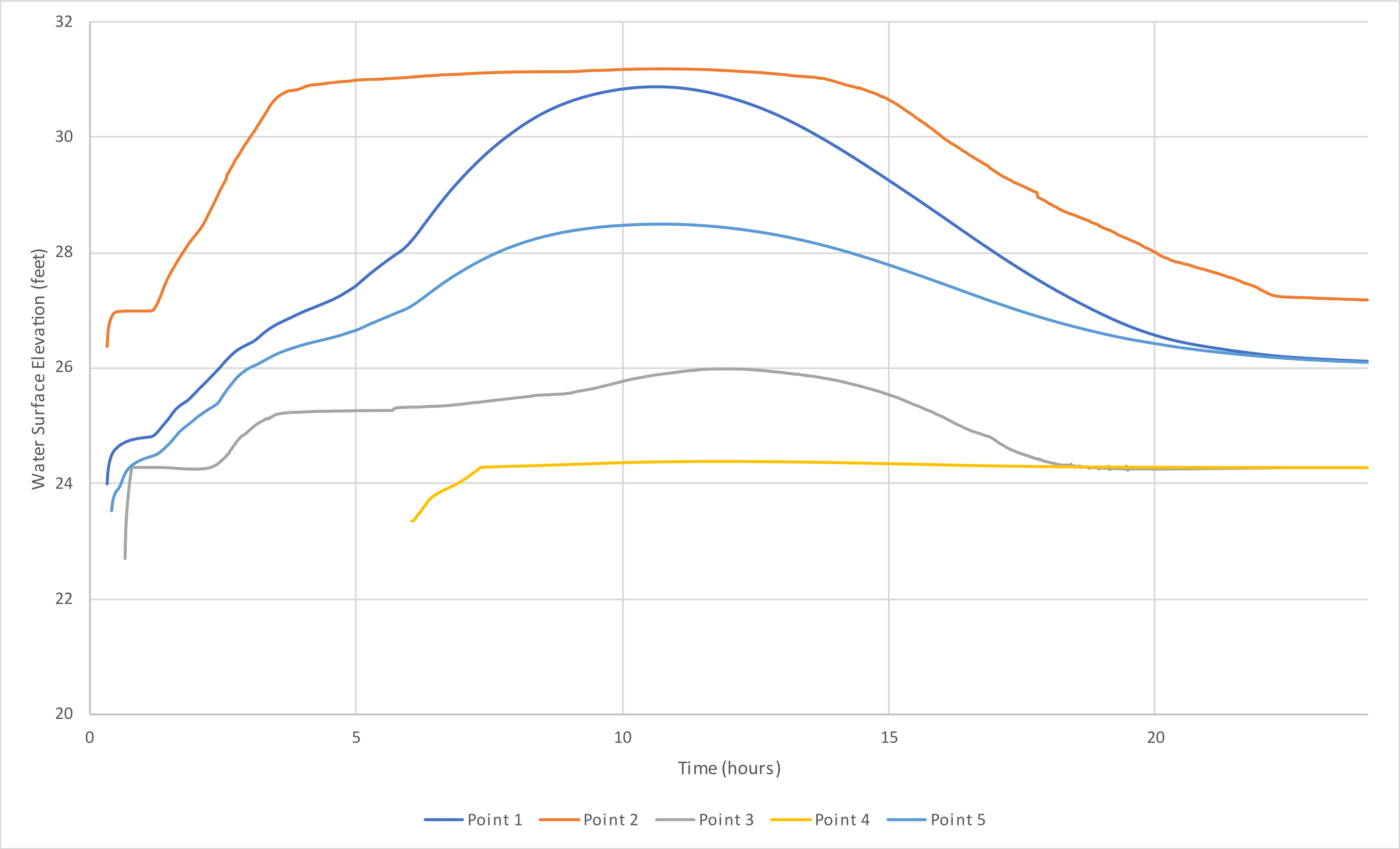

Figure I17: Proposed-conditions 100-year UNT to Wenzel monitor points

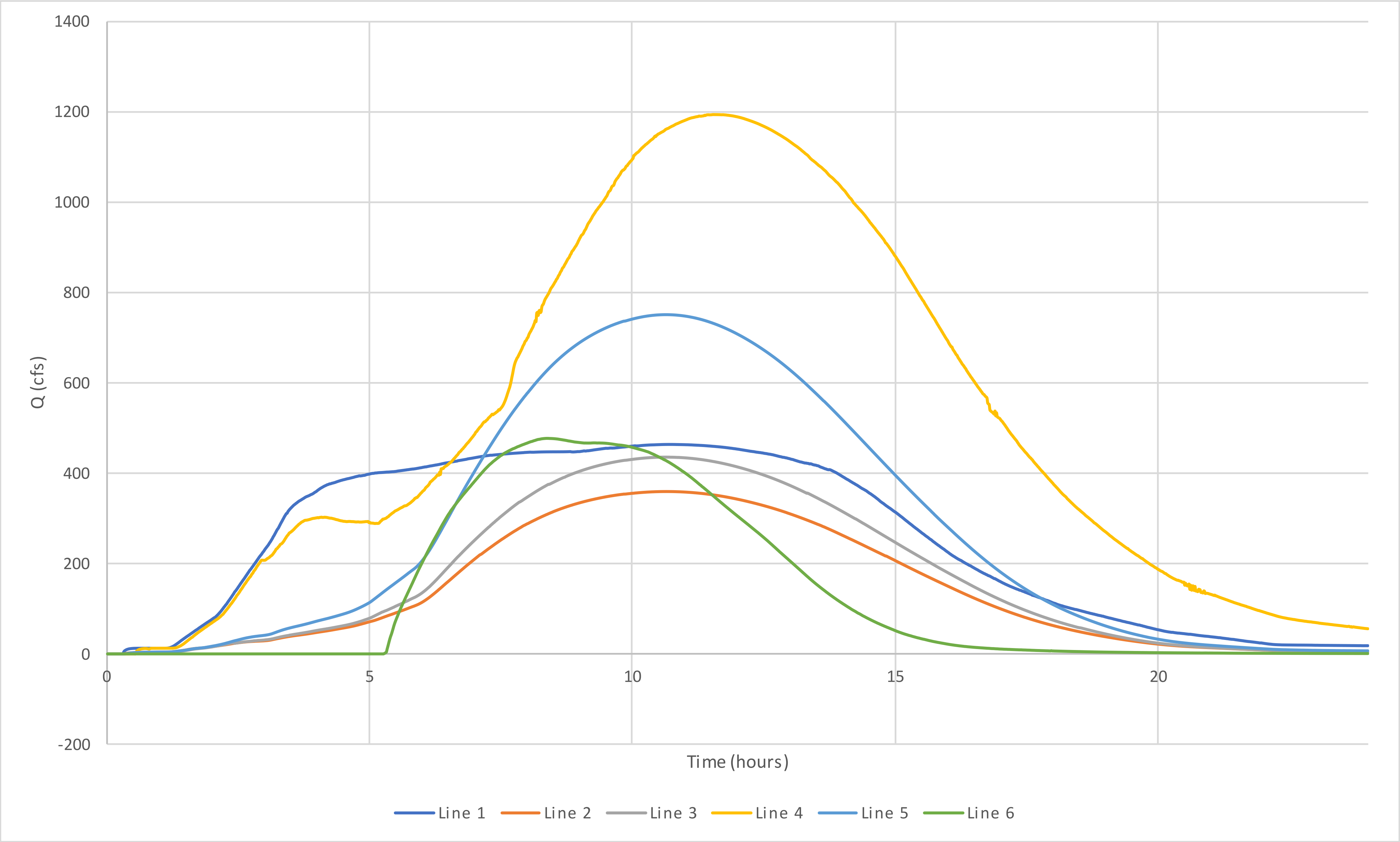

Figure I18: Proposed-conditions 100-year UNT to Wenzel monitor lines

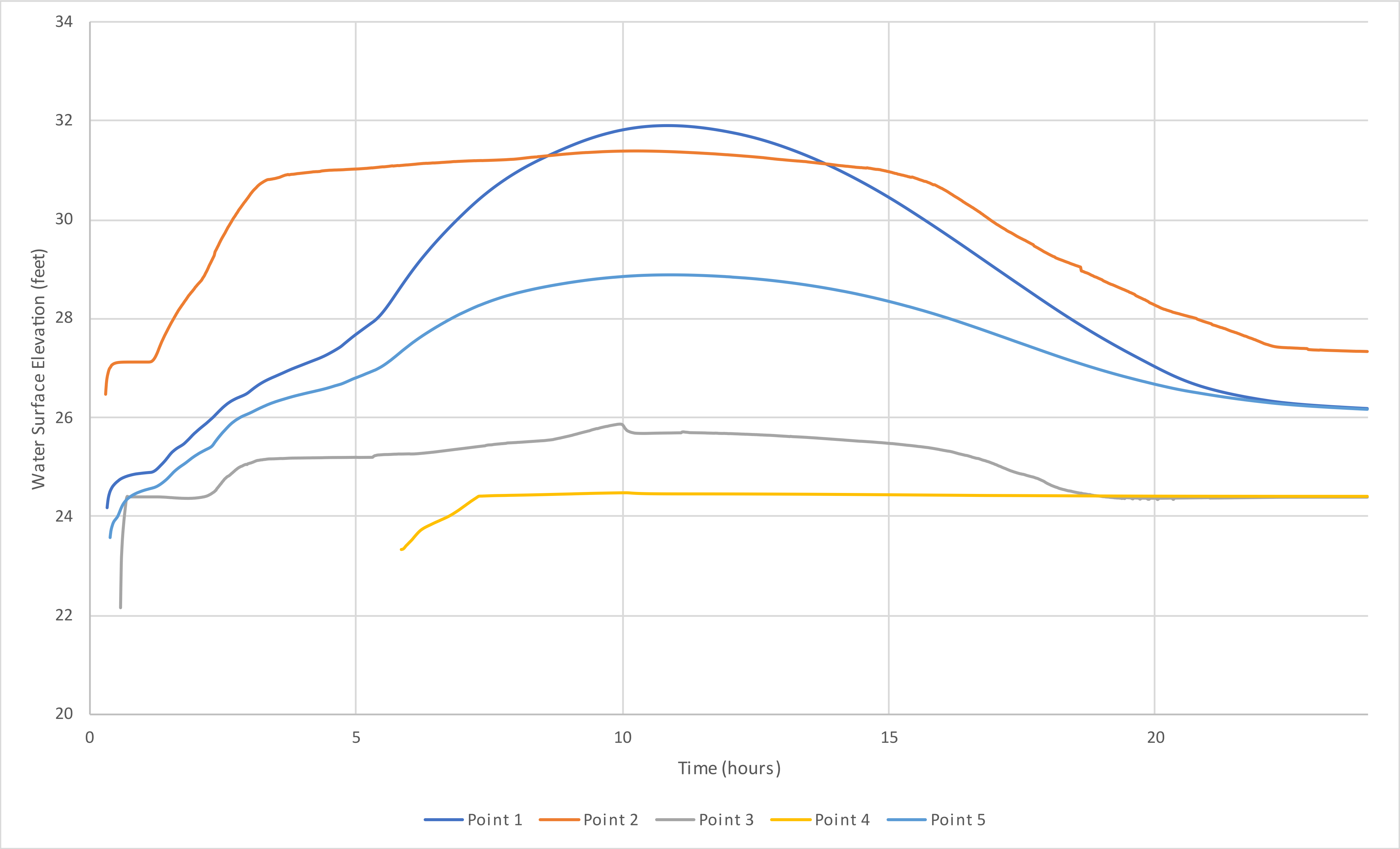

Figure I19: Proposed-conditions 500-year UNT to Wenzel monitor points

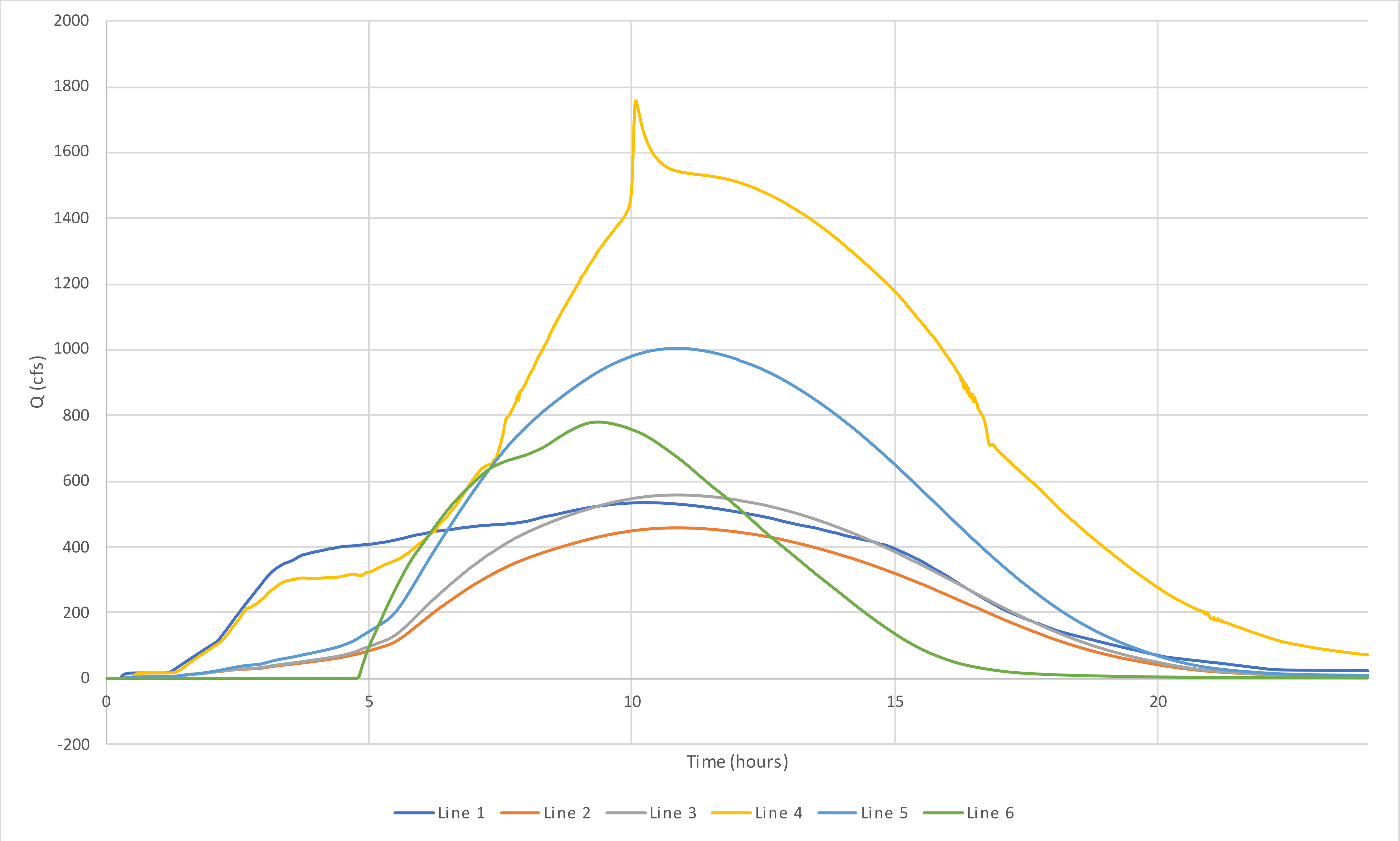

Figure I20: Proposed-conditions 500-year UNT to Wenzel monitor lines

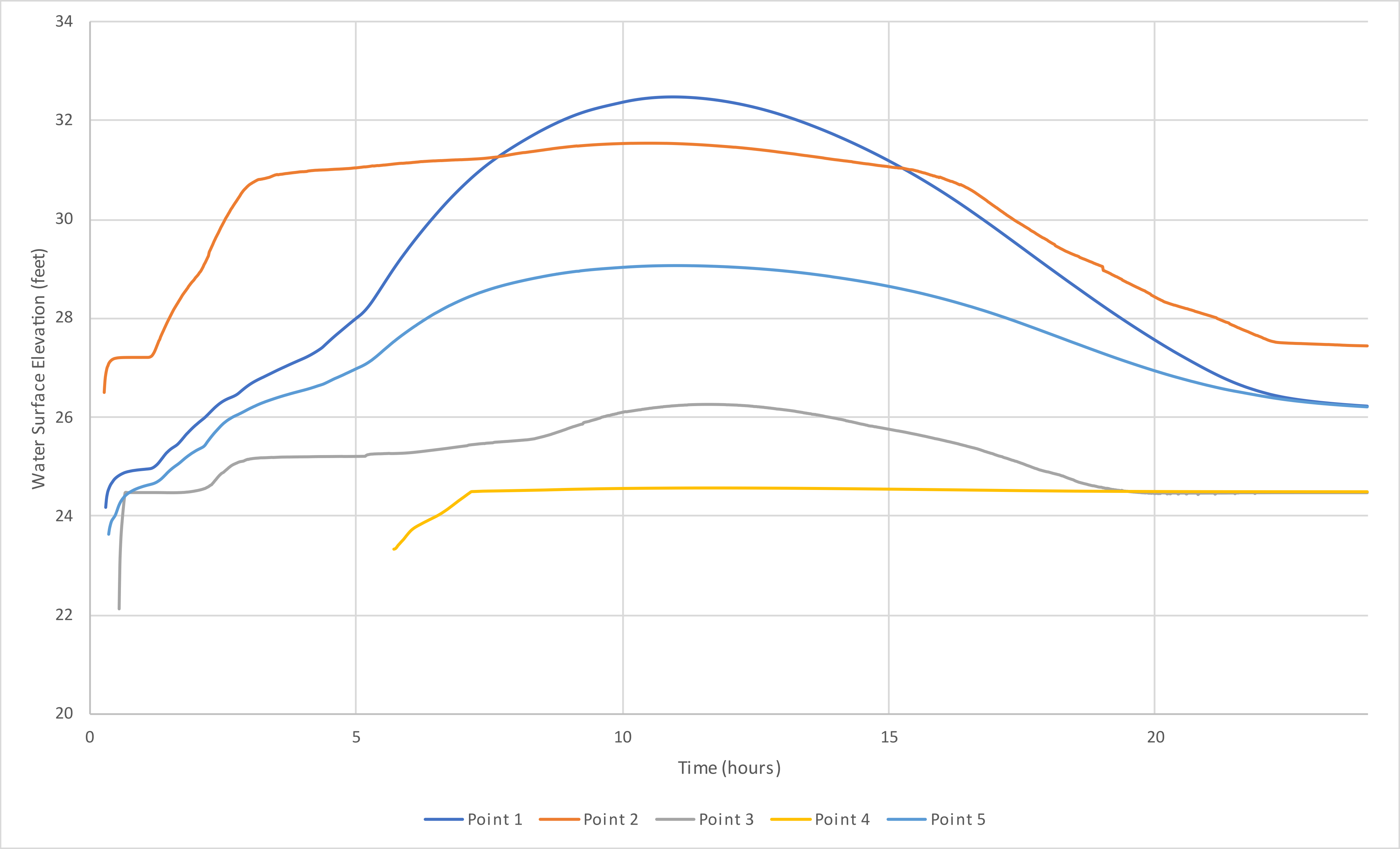

Figure I21: Proposed-conditions 2080 projected 100-year UNT to Wenzel monitor points

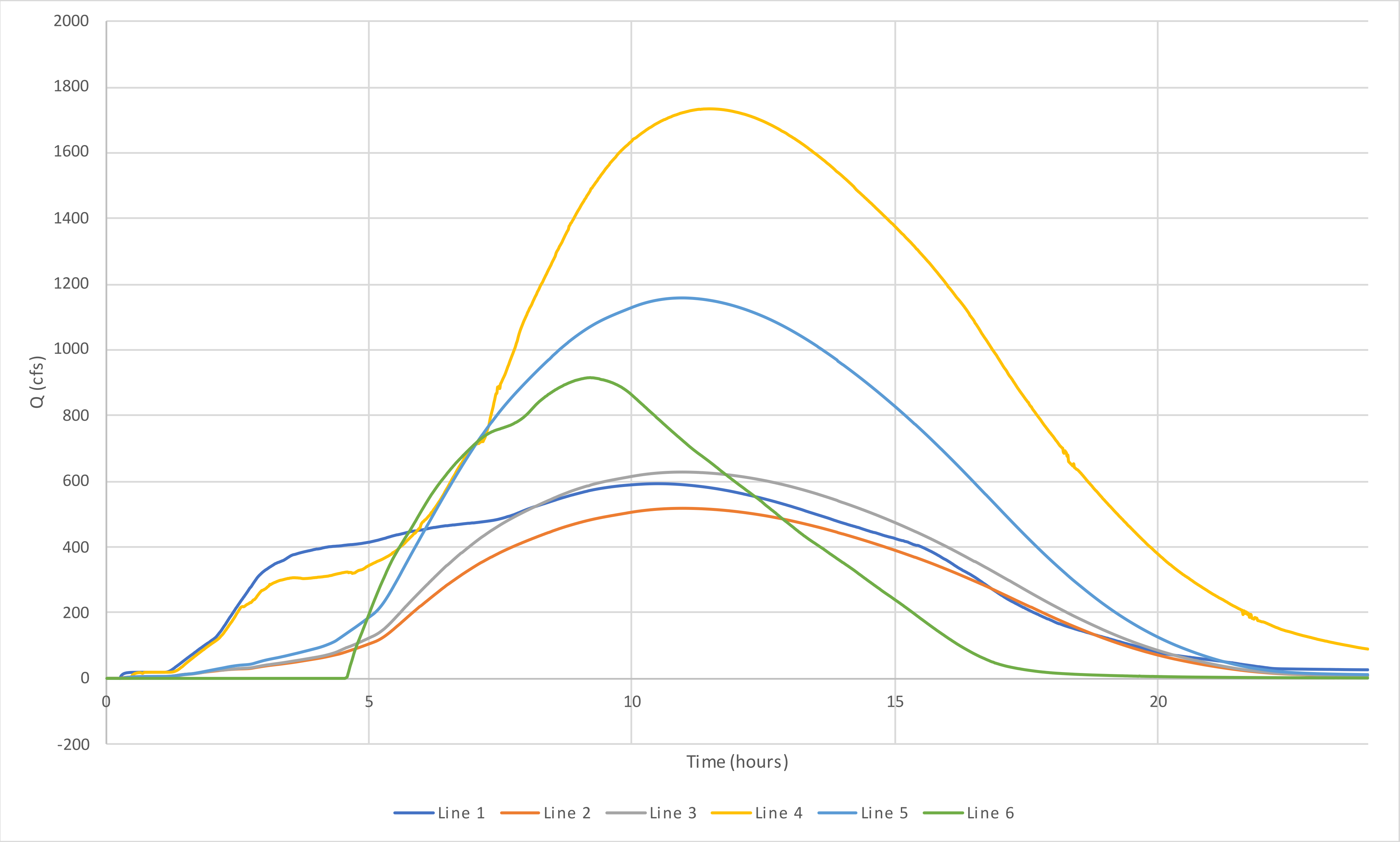

Figure I22: Proposed-conditions 2080 projected 100-year UNT to Wenzel monitor lines

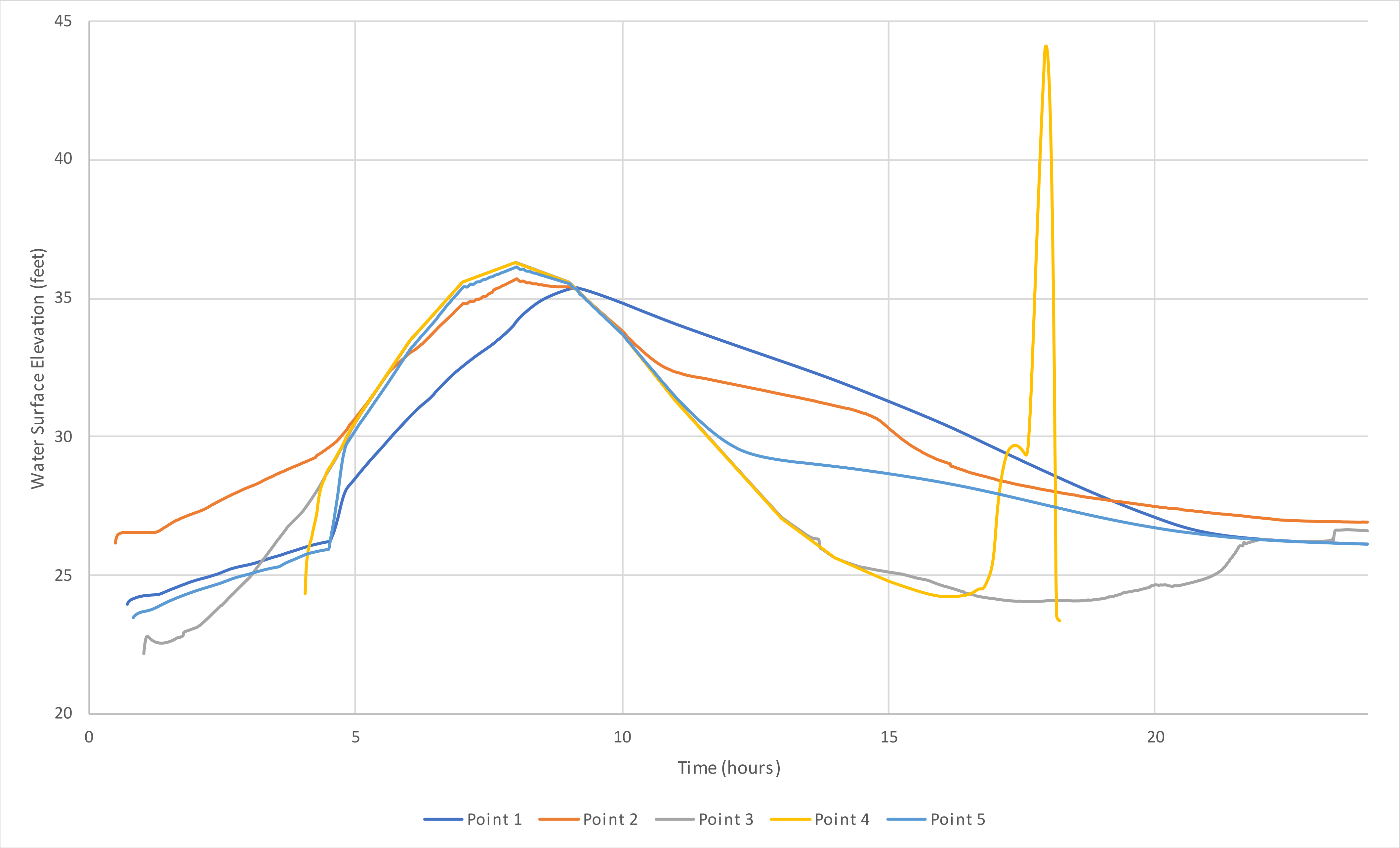

Figure I23: Proposed-conditions 2-year UNT to Wenzel 100-year Chehalis River monitor points

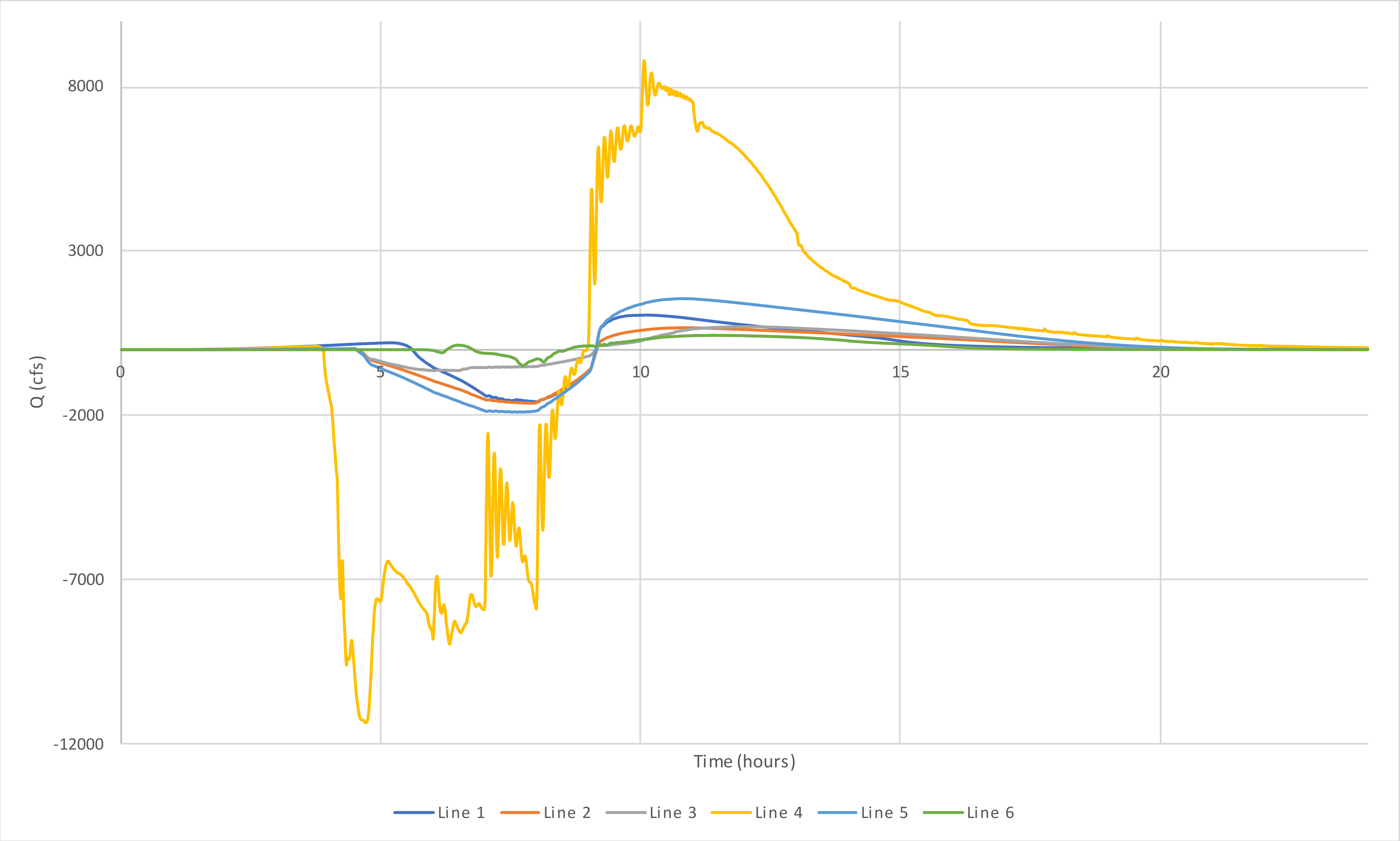

Figure I24: Proposed-conditions 2-year UNT to Wenzel 100-year Chehalis River monitor lines

Appendix J: Reach Assessment (Not Used)

A reach assessment was not completed for this location.

Appendix K: Scour Calculations

Scour in channel bend, 2yr UNT Event
Source: WDFW, App E

Thorne Equation (for gravel beds)

$d = y_1[1.07 - \log(R_c/W-2)]$ — for $2 < R_c/W < 22$

input data in blue:	value =	source
y_1 = average flow depth directly upstream of the bend (ft)		from HEC RAS
W = width of flow (bankfull for high flows) (ft)		from HEC RAS
R_c = radius of curvature at channel centerline (ft)		measured from CAD

Calculated values:		**value =**	
	R_c/W =	#DIV/0!	**#DIV/0!**
maximum depth of scour below local stream bed elevation	d =	#DIV/0!	ft

Maynard Equation (for sand beds)

input data in blue:	value =	source
R_c = Centerline radius of the bend, (ft,m)	33	measured from CAD
W = Width of the channel at the bend, (ft,m)	12	from HEC RAS
A = Cross sectional area upstream of bend (ft^2, m^2)	38.98	from HEC RAS
W_u = Channel width upstream of bend, (ft,m)	12	from HEC RAS
Dm = Measured water depth in bend, (ft,m)	3.15	from HEC RAS

D_{mnc} = Ave water depth in the cross section upstream of bend, (ft,m) — 3.2

checks for valid use of this method:

1) Rc/W should be > 1.5	Rc/W =	2.8	**OK**
2) Rc/W should be < 10	Rc/W =	2.8	**OK**
3) Overbank depth should be less than 20% of main channel depth			

Computation:

$$Dmxb = Dmnc\left[1.8 - 0.051\left(\frac{Rc}{W}\right) + 0.0084\left(\frac{W}{Dmnc}\right)\right] = 5.5 \text{ feet (m)}$$

Scour Depth = 2.3 feet (m)

(Water depth at scour - Water depth w/o scour)

Scour in channel bend, 100yr UNT Event
Source: WDFW, App E

Thorne Equation (for gravel beds)

$d = y_1[1.07 - \log(R_c/W-2)]$ for $2 < R_c/W < 22$

input data in blue:	value =	source
y_1 = average flow depth directly upstream of the bend (ft)		from HEC RAS
W = width of flow (bankfull for high flows) (ft)		from HEC RAS
R_c = radius of curvature at channel centerline (ft)		measured from CAD

Calculated values:		**value =**		
	R_c/W =	#DIV/0!		**#DIV/0!**
maximum depth of scour below local stream bed elevation	d =	#DIV/0!	ft	

Maynard Equation (for sand beds)

input data in blue:	value =	source
R_c = Centerline radius of the bend, (ft,m)	33	measured from CAD
W = Width of the channel at the bend, (ft,m)	12	from HEC RAS
A = Cross sectional area upstream of bend (ft^2, m^2)	77.32	from HEC RAS
W_u = Channel width upstream of bend, (ft,m)	12	from HEC RAS
Dm = Measured water depth in bend, (ft,m)	6.5	from HEC RAS

D_{mnc} = Ave water depth in the cross section upstream of bend, (ft,m) 6.4

checks for valid use of this method:			
1) Rc/W should be > 1.5	Rc/W =	2.8	**OK**
2) Rc/W should be < 10	Rc/W =	2.8	**OK**
3) Overbank depth should be less than 20% of main channel depth			

Computation:

$$Dmxb = Dmnc\left[1.8 - 0.051\left(\frac{Rc}{W}\right) + 0.0084\left(\frac{W}{Dmnc}\right)\right] = 10.8 \text{ feet (m)}$$

Scour Depth = 4.3 feet (m)
(Water depth at scour - Water depth w/o scour)

Appendix L: Floodplain Analysis

A flood risk assessment will not be completed for this site.

Appendix M: Scour Countermeasure Calculations (Not Used)

Traditional scour countermeasures are not used at this crossing.